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EDITORIALS AND ANNOTATIONS

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In 1942 William Rogers succeeded E. G. Brackett as Editor of the *Journal of Bone and Joint Surgery*, then the official publication of the American Orthopaedic Association alone. A few years later, when approaches were made by the British Orthopaedic Association to consider sharing the full responsibility and duty of joint publication instead of simply accepting the hospitality that had so long been enjoyed, William Rogers proved to be a tower of strength and inspiration. From the time of my first conversations with him in trains and hotels in America, in preliminary discussions at House-in-the-Wood, Surrey, and in the final stages of agreement in the Royal College of Surgeons of England, he never failed to share supreme confidence in the plan of co-publication by the nations of the English-speaking world. Indeed he urged us

repeatedly to hold foremost the star of international and world influence for the benefit of mankind as a whole. Never before in the history of surgical publication had such an ideal been considered, still less achieved, and we owe an immeasurable debt to William Rogers for his great and leading part.

Now though deeply regretting the illness that has made Bill Rogers retire, always with the enduring comfort of his wife Emily, we applaud and acclaim him as Editor-in-Chief Emeritus of our Journal—a title never before bestowed, which we trust will long be enjoyed. He has been succeeded as American Editor by Thornton Brown to whom we send greetings and good wishes for the success of his onerous duty. To Robert W. Johnson, Jun., who has now given place to James S. Speed as Chairman, we send loyal messages of goodwill with an assurance of our deep gratitude for the devotion of his service over the years that culminated recently, when the tenth anniversary was celebrated, in an assurance of long continued and happy collaboration.

REGINALD WATSON-JONES.

PROGNOSIS IN TRACTION LESIONS OF THE BRACHIAL PLEXUS

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The complete supraclavicular traction injury of the brachial plexus is one of bad prognosis among traction lesions of nerves. Recovery is always incomplete and even in the most favourable cases takes a long time, and distressing pain is often a feature. The injury is uncommon, but when it happens it causes severe disability, because those affected are usually young men with a long working life ahead of them. Prominent among the difficulties in the handling of these cases is that of assessing prognosis. It is clearly desirable to know as early as possible whether useful recovery is going to occur or whether none can be expected. In the former case expectant treatment may be advised, whereas in the latter amputation can be done or reconstruction started without delay. In this investigation some of the factors have been studied which may have a bearing on prognosis.

MATERIAL

In the ten years 1949-58 twenty-nine patients with complete supraclavicular traction lesions of the brachial plexus have been seen and studied at the Royal National Orthopaedic Hospital. Each presented with, or later showed evidence of, a complete degenerative lesion

TABLE I

AGE GROUPS: TWENTY-NINE PATIENTS WITH TRACTION LESIONS OF THE BRACHIAL PLEXUS

Age (*years*)	Number of patients
5 to 15	3
16 to 25	20
26 to 40	6

TABLE II

MODES OF INJURY: TWENTY-NINE PATIENTS WITH TRACTION LESIONS OF THE BRACHIAL PLEXUS

Nature of injury	Number of patients
Motor cycle accident	22
Pedal cycle accident	4
Run over by car	1
Arm caught in machine	2

affecting the whole plexus in its supraclavicular part. Clinical evidence was usually supplemented by tests of the electrical excitability of the affected muscles and by tests of cutaneous reflexes. Electromyography was used only occasionally. In a number of the cases additional confirmatory evidence was provided by sweating tests and tests of vasomotor activity.

All but one of the patients were male; most of them at the time of injury were between sixteen and twenty-five years of age (Table I); most had been injured while riding a motor cycle (Table II). The right arm was involved in twenty-three patients and the left in six. The periods of observation were from three to ninety-three months (Table III), the average being twenty-seven months. One patient (length of follow-up fourteen months) could not be traced, and one (length of follow-up seventy-five months) was unable to attend for examination. A third patient went to America for further treatment soon after investigation at the Royal

TABLE III

PERIODS OF OBSERVATION: TWENTY-NINE PATIENTS WITH TRACTION LESIONS OF THE BRACHIAL PLEXUS. (In cases in which amputation was performed, period of observation is taken as being up to the time of amputation)

Period of observation (*months*)	Number of patients
0 to 3	1
4 to 6	3
7 to 12	1
13 to 24	6
25 to 36	8
37 to 48	—
49 to 72	5
over 72	5

TABLE IV

INTERVAL BETWEEN INJURY AND ATTENDANCE AT THE ROYAL NATIONAL ORTHOPAEDIC HOSPITAL: TWENTY-NINE PATIENTS WITH TRACTION LESIONS OF THE BRACHIAL PLEXUS

Interval	Number of patients
Under 1 month	3
,, 2 months	8
,, 3 months	2
,, 6 months	8
,, 12 months	6
,, 24 months	2

National Orthopaedic Hospital. He was treated in the Neurological Institute of the Presbyterian Hospital, New York, by Dr John E. Scarff, who has kindly provided a follow-up report. The patients were first seen at the Royal National Orthopaedic Hospital at times ranging from three hours to twenty months after injury (Table IV).

METHODS OF STUDY

Clinical—Voluntary muscular power was tested and recorded using the system recommended in the report of the Nerve Injuries Committee of the Medical Research Council (1954).

A " useful " degree of recovery of an individual muscle was taken to be recovery to Grade 3 or better. Because of the complexity produced by the number of muscles involved, this information was condensed, one point being given for recovery to Grade 3 or better of each of the following muscles or groups of muscles: 1) muscles controlling scapular movements; 2) abductors of the scapulo-humeral joint; 3) lateral rotators of the scapulo-humeral joint; 4) adductors of the scapulo-humeral joint; 5) flexors of the elbow; 6) triceps; 7) flexors of the wrist; 8) flexors of the fingers.

The extensor muscles of the wrist and fingers and the intrinsic muscles of the hand were not included because in this series no useful recovery of these muscles was seen. The grade of total motor recovery was designated by the letter M followed by the number of points. Difficulty in assessment was caused by the frequent occurrence of cross-innervation causing simultaneous contraction in two muscles of opposing actions. The muscles most commonly affected in this way were the triceps and biceps, and the triceps and pectoralis major. The latter action was, of course, troublesome when the pectoralis muscle had been transferred to act as a flexor of the elbow. Nevertheless it seemed fair to give a point to each muscle of a pair so affected, for the less useful muscle can generally be transferred to reinforce the action of its antagonist. Thus, when the biceps and the triceps are opposing each other, strong active flexion of the elbow can be obtained by transferring the triceps into the biceps (Seddon 1957).

Because of the uniformly poor quality and restricted extent of sensory recovery, this was simply recorded as follows: S.0=no recovery of sensation below the elbow; S.1=partial or complete recovery of any modality of superficial sensibility in the forearm; S.2=partial or complete recovery of any modality of superficial sensibility in the forearm and hand.

In all cases evidence of paralysis of the cervical sympathetic system was sought, and the presence, severity and duration of pain were recorded.

Most of the patients had their chests screened at the time of the final examination, but in most cases direct evidence is lacking as to the state of the diaphragm soon after injury.

Associated injuries were noted and classed as follows: bony injury in the affected arm; vascular injury in the affected arm; concussion; injuries elsewhere in the body.

The patients were asked whether they had returned to work and, if so, what sort of work they were doing.

Operative—In one case the brachial plexus was explored elsewhere at the time of primary operation on the associated compound fracture of the clavicle. In fifteen others the plexus was explored at an elective operation to determine prognosis. The operative technique used was that described in an earlier paper (Bonney 1954*a*). No mortality was associated with this operation, and the only complication encountered was pulmonary collapse, which occurred in one case after the accidental opening of the apical pleura. In no case was it possible even to contemplate repair of the neural lesion, the extent and complexity of the damage always preventing resection and repair. In the case of the patient who came under the care of Dr Scarff, the roots of the brachial plexus were explored by cervical hemilaminectomy.

Histological—In twelve of the cases in which exploration was done, funicular biopsies were taken from one or more nerves of the plexus.* The histology of these has been studied by Dr Hubert Sissons and Dr Mary Catto.

Techniques of preparation: In addition to the ordinary techniques, the Lissamine fast red method (Lendrum 1947), silver impregnation methods (Holmes 1947*a*, Glees 1954) and the myelin staining technique (Holmes 1947*b*) were used.

* The brachial plexus is formed by the union of the anterior primary rami of the lower four cervical nerves and the greater part of the first thoracic nerve. These nerves constitute the roots of the plexus (Johnston and Whillis 1946). To avoid confusion, the roots of the plexus will here be referred to throughout as " nerves " in order to distinguish them from the anterior and posterior roots.

Examination of axon reflexes—The so-called axon reflexes of the skin of the affected limb were examined by the techniques described in an earlier paper (Bonney 1954*a*). The responses in the forearm were produced by pricking in through a drop of a 1 per cent solution of histamine acid phosphate. On the affected side six such punctures were usually made—two on the ulnar side of the forearm, two on the radial side of the forearm, one on the ulnar side of the dorsum of the hand and one on the radial side of the dorsum of the hand. As a control, one or two pricks were usually made in similar dermatomes of the skin of the healthy forearm and hand. One of two responses was regularly produced: a positive reaction with local vasodilation and the formation of a " flare " (triple response), or a negative response with only local vasodilation and whealing.

Because of the difficulty of assessing the response of the digital skin to intradermal injection of histamine, the axon reflexes of the fingers were examined by measuring their vasomotor response to cold water. The technique previously described (Bonney 1954*a*), in which heat-flow discs (Hatfield 1950) are used to measure the vasomotor response to immersion at temperatures of from 2 to 5 degrees centigrade, was used without modification. The reactions of the second and fifth digits of both hands were usually compared.

THE GENERAL PICTURE OF RECOVERY

In assessing " final " recovery only those nineteen patients will be considered whose period of observation was twenty-four months or longer. One of these had an amputation

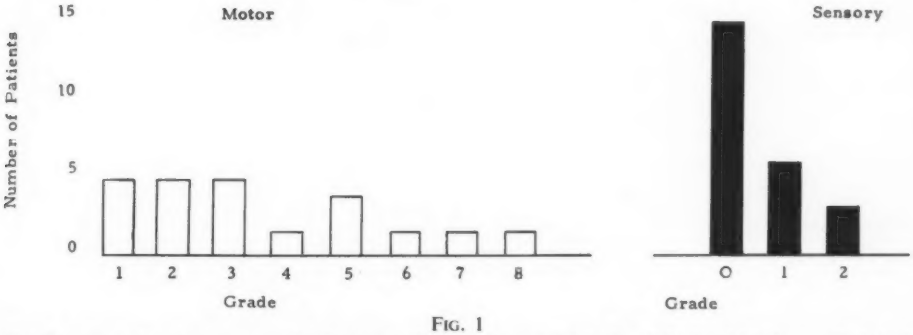

FIG. 1

Total motor and sensory recovery in nineteen patients with traction injuries of the brachial plexus. Period of observation twenty-four months or longer.

through the arm thirty-four months after injury and one had an amputation through the forearm fifty-four months after injury. The quality of both motor and sensory recovery was extremely poor (Fig. 1), more than half of the patients obtaining motor recovery of Grade M 3 or lower and insignificant recovery of sensibility. The three patients who had the best return of sensibility had also motor recovery of grade M 5 or better.

Analysis of motor recovery (Fig. 2)—In all nineteen patients there was recovery of normal or of a useful degree (M.R.C. Grade 3 or over) of power in the trapezius, rhomboids and serratus anterior. In many of these cases one or more of these muscles was seen to be contracting either normally or with reduced power soon after the injury, and it is certain that often they were wholly or partly spared. It seems certain too that even if they are initially involved they are certain to attain a useful degree of recovery. Recovery of the pectoralis major to Grade 3 or better was seen in twelve cases. This is a matter of some practical importance, for a strong pectoralis major enables the patient to grip objects between his arm and his chest or offers the chance of transfer to give active flexion of the elbow. There were only three instances of

useful recovery of the deltoid, and only two of useful recovery of the lateral rotators of the shoulder. Useful recovery of the biceps was seen in six cases, in two of which the biceps and triceps contracted simultaneously to lock the elbow. In these two, transfer of the triceps conferred excellent power of active flexion of the elbow. Useful recovery of the triceps was seen in six cases, associated in four of these with good recovery of the biceps. Recovery to M.R.C. Grade 3 or better of one or more of the wrist flexors was seen in five cases and of one or more of the finger flexors in four. No useful recovery was seen in the extensor muscles

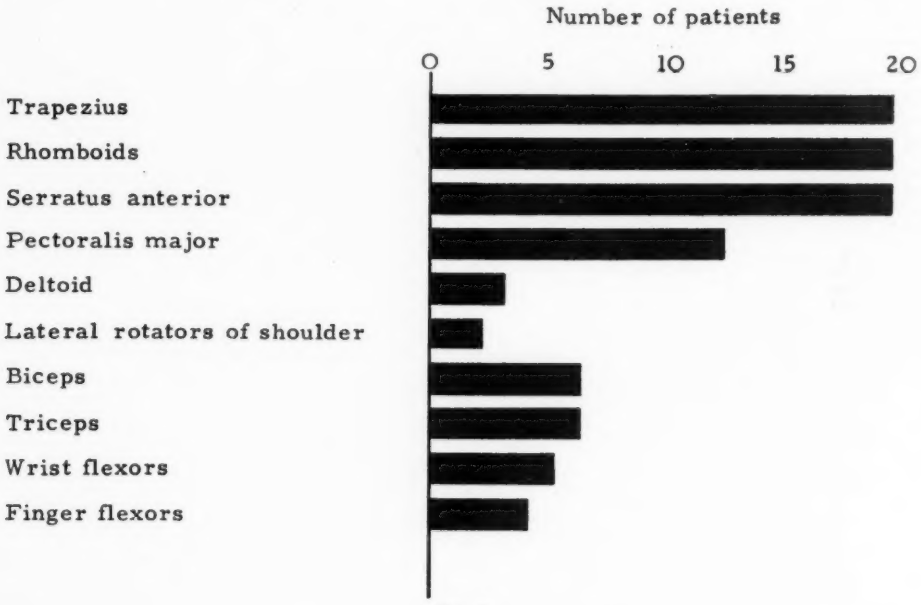

FIG. 2

Analysis of motor recovery to M.R.C. Grade 3, or better. Nineteen patients with traction injuries of the brachial plexus. Period of observation twenty-four months or longer.

of the wrist or fingers, nor in the intrinsic muscles of the hand. The general pattern of the timing of motor recovery is shown in Figure 3, which relates to all out of the twenty-eight patients from whose notes this information could be extracted. The chart records the time when contraction was first noticed of a muscle which later went on to regain useful function. The large accumulation of trapezius, rhomboids and serratus anterior to the left of the chart is really an indication of the sparing of these muscles in a number of cases. It is of some interest that a good deal of recovery starts between the twelfth and twenty-fourth months, and that recovery can still start after denervation which has lasted for more than twenty-four months.

Analysis of sensory recovery—Not only was the extent of sensory recovery poor but its quality was extremely defective. Interpretation of the nature of the stimulus was usually at fault and localisation was poor. Appreciation of heat or cold was usually delayed, and deep sensibility was generally absent. In the most favourable cases the return of sensibility was only good enough to protect the hand from accidental damage. In spite of this generally poor sensory recovery, serious nutritional changes were not seen: in one case a small ulcer had developed and in another there was blistering from an unnoticed burn.

Even with this considerable disability all but one of the nineteen patients had returned to work. Only those with the best degree of recovery made any effective use of the damaged

limb. Most of them, even after reconstructive surgery, would keep the affected hand in the pocket and would use only the healthy arm. The most useful actions of the limb were adduction at the shoulder and flexion at the elbow, each of these allowing carrying by the affected arm. Recovery of the flexors of the wrist and fingers was of little functional significance in the

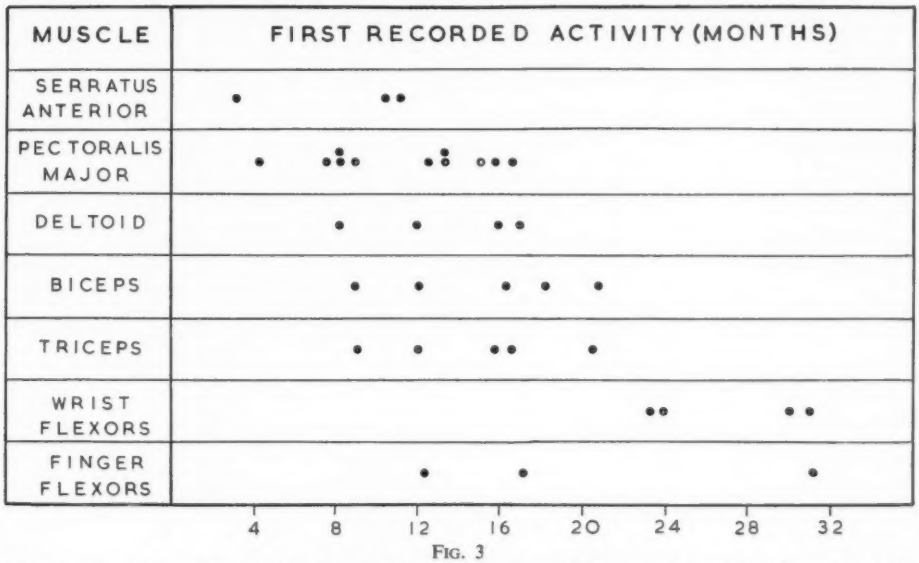

FIG. 3

Motor recovery in traction injuries of the brachial plexus. Time of first recorded activity of muscles which later went on to recovery of M.R.C. Grade 3 or better.

absence of recovery of the extensors. In spite of these many disadvantages, the arm with the best degree of recovery was, after any necessary reconstruction, definitely superior to an artificial limb on an above-elbow stump.

FACTORS INFLUENCING PROGNOSIS

GENERAL CONSIDERATIONS

Even when one considers the generally poor prognosis for traction lesions of nerves, the results in such injuries of the brachial plexus seem extraordinarily bad. It is not sufficient to argue that the distance of the lesion from the point of innervation determines the defective recovery, for recovery of sensibility is not subject to the same limitation of time as is return of motor function. The anatomical complexity of the supraclavicular part of the brachial plexus may well account for confusion of regenerating axons, but again one would expect better recovery of sensibility, however ill-localised. The position of the plexus, running between the spinal column and the mobile shoulder girdle, is likely to determine severe damage when the shoulder girdle is wrenched away from the trunk. Indeed, the violence is sometimes so great that the plexus is actually torn apart or avulsed from its proximal attachments. There still remain to be explained those frequent cases in which at exploration the nerves of the plexus are seen to be in continuity and seemingly little damaged but in which little or no recovery occurs. The idea that the neural damage is often intradural was put forward by Jefferson (1930), and since then White and Hanelin (1954) have obtained from myelography further evidence in support of this suggestion. In each case, therefore, it is necessary to know not only the severity of the local damage but also the site of the lesion. If the lesion were one in continuity distal to the intervertebral foramen the outlook would be favourable;

if it were an intradural lesion the prognosis would be bad, for there would be a considerable liability to avulsion of the roots from the cord. It is certain that in most cases of traction lesion of the plexus the site and the extent of damage vary between the individual nerves. The objective then is to determine for each nerve the site and extent of the damage, bearing in mind that placing of the lesion within the theca implies severe damage.

CLINICAL FEATURES WITH A BEARING ON PROGNOSIS

Distribution of the paralysis—Knowledge of the distribution and the severity of the paralysis will not allow us to go beyond the diagnosis of a degenerative lesion to say whether the nerves have been stretched or pulled apart. It will, however, give valuable information about the site of the lesion of the fifth and sixth cervical nerves. The nerve to the rhomboids arises from the fifth cervical nerve soon after it leaves the intervertebral foramen, and the origin of the nerve to serratus anterior from the fifth, sixth and seventh cervical nerves is similarly

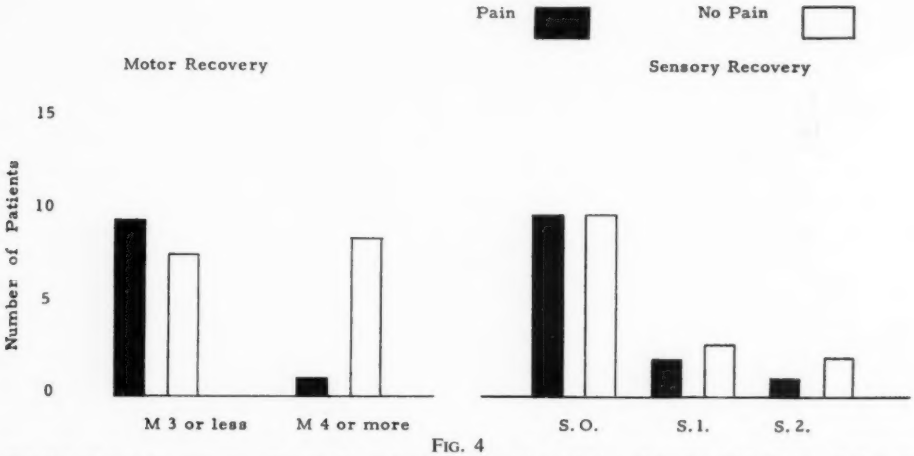

FIG. 4

Relation of pain to recovery. Twenty-five patients with traction injuries of the brachial plexus. Period of observation in all but one was twelve months or more. In the twenty-fifth the hopelessness of the prognosis was confirmed at cervical laminectomy.

placed. Sparing or early recovery of the rhomboids and serratus anterior is therefore good evidence that the lesion of the fifth and sixth cervical nerves is extradural. Such evidence was in fact present in all but two cases of the present series.

The evidence available from this study is not sufficient for conclusions to be drawn regarding the significance of involvement of the cervical plexus and of the phrenic nerve. What evidence there is suggests that such involvement is not related to the prognosis of the lesion of the brachial plexus.

Pain—Some pain was present in every case during the early stages. Severe or moderately severe pain lasting for more than three months was experienced by twelve patients. The pain, usually situated in the forearm or hand, was described as occurring in spasms. These spasms often seemed to be brought on by handling of the affected limb or by movements of the shoulder girdle, but otherwise they were unaffected by external circumstances. This pain seemed to be distinct from the more common and less severe aching pain experienced when the limb was chilled. It was notably unaffected by analgesic drugs or by other methods of relieving pain, but usually subsided over the course of years. Since the possibility arises that the severity and persistence of pain may be determined by the severity of the neural damage, the results in twelve patients with pain were compared with those in thirteen patients without

pain (Fig. 4). Twenty-four of these patients have been under observation for twelve months or longer. In the twenty-fifth the hopelessness of the prognosis was demonstrated at the sixth month by the finding at cervical laminectomy of avulsion of the roots of the plexus. Of those patients with pain, eleven had motor recovery of grade M.3 or less. Of those without pain, or with less severe pain, more than half had motor recovery of grade M.4 or better. There was no difference in sensory recovery between the two groups. The severity of pain is not, however, a very agreeable criterion on which to base an assessment of prognosis, because it depends so much on the character of the patient and on the clinician's approach.

Horner's syndrome—As Barnes (1949) has pointed out, the presence of a Horner's syndrome is generally a bad sign, and its absence is often a favourable indication. Four patients of the present series showed no evidence of involvement of the cervical sympathetic nerves and three of these went on to recovery of grade M.5 or better. It seems probable that the Horner's syndrome is produced by the violent movement of the first thoracic nerve tearing its white

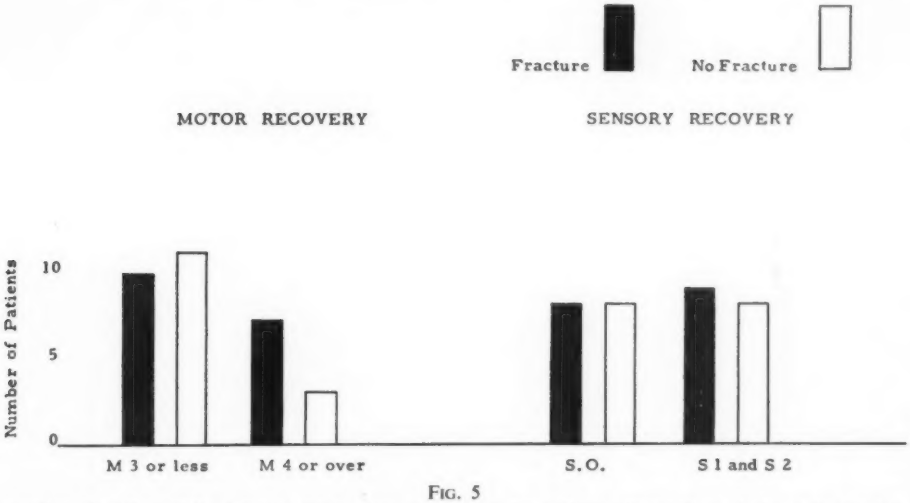

FIG. 5

Relation of fracture of the affected limb to recovery. Twenty-five patients with traction injuries of the brachial plexus. Period of observation in all but one was twelve months or more. In the twenty-fifth the hopelessness of the prognosis was confirmed at cervical laminectomy.

ramus to the stellate ganglion. Disturbance of cervical sympathetic function would thus indicate a severe lesion of the first thoracic nerve and would suggest the likelihood of similarly severe damage to the other nerves of the plexus. This explanation is not entirely satisfactory, because in two patients the Horner's syndrome first appeared some two to three weeks after injury. This late onset of paralysis suggests that in these cases axonal degeneration was necessary for the production of the syndrome.

Method of injury—It is possible that the high-velocity injury resulting from an accident on a motor cycle carries a worse prognosis than that resulting from the slower traction of having the arm caught in a machine. Not enough cases of the latter type of injury have been seen to substantiate this argument, but it is interesting that the two patients whose injuries were produced in this manner made comparatively good recoveries (M.5, S.0, and M.5, S.2).

Associated injuries—It seemed likely that an associated fracture of the paralysed limb might imply a severe degree of neural damage and hence a bad prognosis. Fourteen patients suffered a fracture of the scapula, of the humerus, of the radius and ulna or of several bones in the affected limb. Twelve have been under observation for twelve months or more and in the

thirteenth the roots of the plexus were found at cervical laminectomy to have been avulsed from the spinal cord. Their degree of recovery, both sensory and motor, shows little difference from that seen in twelve comparable patients who had no fracture of the affected upper limb (Fig. 5). There is a similar lack of correlation between prognosis and other associated injuries such as concussion and fractures elsewhere in the body.

THE VALUE OF OPERATIVE EXPLORATION

The purpose of operation is never more than to get better information about the site of the lesion and the severity of the damage than can be obtained by clinical examination. At the beginning, two questions have to be asked: how much of the plexus should be explored, and how accurately can we interpret the findings at operation? As regards the first question: examination of Figure 2 will show that motor recovery for the most part occurs in the distribution of the fifth and sixth cervical nerves, a moderate amount in the distribution of the seventh cervical nerve, rather little in that of the eighth cervical nerve and probably none in the territory of the first thoracic nerve. It might therefore seem correct to explore only the fifth and sixth cervical nerves and the upper trunk, because the greater part of any possible recovery will be that mediated through these nerves. It is, however, a fact that such a limited exposure of the plexus may occasionally lead to misinterpretation of the findings, the upper trunk being reported as severed and later recovery occurring in its distribution. A really clear view of the fifth, sixth and seventh cervical nerves under the special conditions of a traction lesion of the plexus can be obtained only by division of the scalenus anterior and displacement of the subclavian artery. The eighth cervical and the first thoracic nerves cannot be seen at all unless this is done. It is suggested therefore that when exploration is done it should be complete enough to afford a view of the fifth, sixth and seventh cervical nerves. This exposure involves the most difficult step of the operation—the division of scalenus anterior and the mobilisation of the artery—and once this has been done little additional trouble is involved in exposing the eighth cervical and first thoracic nerves. As regards the second question: the interpretation of the operative findings is only easy when part or all of the plexus is found to be torn apart or ripped away from the spinal column. Very often the scarring around and in the damaged plexus makes dissection difficult and dangerous and makes it very difficult to identify individual nerves or, having done this, to assess the degree of damage.

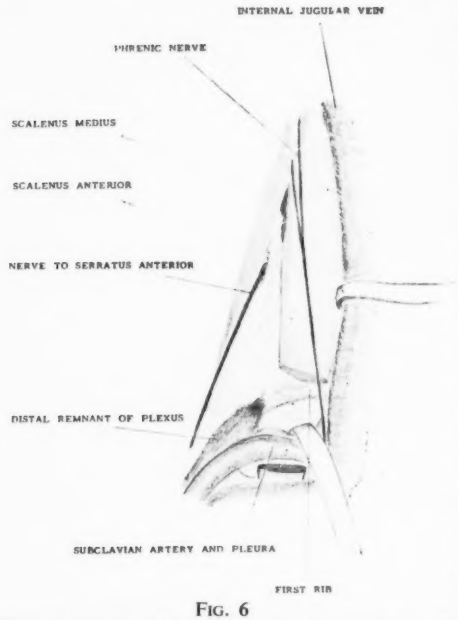

FIG. 6

Operative findings in a case of complete avulsion of the brachial plexus. The only neural elements seen are the nerve to serratus anterior and the phrenic nerve, and a fibrotic remnant of the plexus in relation to the subclavian artery.

In sixteen patients the brachial plexus was explored in the supraclavicular region of the neck, in one case at the time of primary operation on an associated compound fracture of the clavicle and in the other fifteen as an elective procedure. In one case exploration of the plexus was by cervical laminectomy. A tear-apart of the whole plexus was encountered in

TABLE V

PROBABLE MOTOR DISTRIBUTION OF THE NERVES OF THE BRACHIAL PLEXUS

(Only those muscles are included in which in the cases included in Tables VI and IX recovery was seen)

C.5	C.6	C.7	C.8	T.1
Rhomboids	Serratus anterior	Serratus anterior	Pectoralis major (sternal)	Pectoralis major (sternal)
Serratus anterior	Deltoid	Pectoralis major (clavicular)	Flexor carpi ulnaris	
Spinati	Pectoralis major (clavicular)	(Biceps)		
Deltoid	Biceps	Triceps		
Biceps				
Pectoralis major (clavicular)				

TABLE VI

FINDINGS AT OPERATION. FIFTH AND SIXTH CERVICAL NERVES. ELEVEN PATIENTS

Case number	Time interval: injury/operation	Operative findings	Time interval: injury/final state	Motor recovery
3	5 months	Lesion in continuity at lateral border of scalenus anterior	64 months	Scapular MM 4/5 Pectoralis major 4 (clavicular)
4	4 months	Torn at lateral border of scalenus anterior	75 months	Scapular MM 4/5
6	7 months	Torn one inch lateral to scalenus anterior	21 months	Scapular MM 4/5 (A.E. amputation at 21 months)
7	3 months	Lesion in continuity with large hard neuroma	53 months	Scapular MM 3/4 Pectoralis major 3 (clavicular) Biceps 1
10	9 months	Lesion in continuity at lateral border of scalenus anterior	75 months	Scapular MM 4/5 Pectoralis major 4 Deltoid 2 Biceps 2
11	8 months	(Restricted exposure) Only part of plexus found was small lump above clavicle	75 months	Scapular MM 4/5 Deltoid 3 Biceps 3
12	6 months	Torn at lateral border of scalenus anterior	76 months	Scapular MM 4/5 Pectoralis major 3 (clavicular)
20	3 months	Soft lesion in continuity	24 months	Scapular MM 4/5
25	4 months	Hard lesion in continuity	13 months	Scapular MM 4/5 Pectoralis major 4 Spinati 4 Deltoid 3 Biceps 1
28	3 months	Lesion in continuity with firm neuroma	3 months	Serratus 3
29	9 months	In continuity rather thickened	9 months	Serratus 3 Rhomboids 3

three of the first sixteen patients, no neural structures apart from the nerve to serratus anterior and the phrenic nerve being found in the posterior triangle (Fig. 6). In the patient whose plexus was explored at a primary operation, only the first thoracic nerve was seen to be in continuity, the other components of the plexus being torn across. These four patients have been under observation for twelve months or more, and none of them has shown any evidence

TABLE VII

FINDINGS AT OPERATION. SEVENTH CERVICAL NERVE. NINE PATIENTS

Case number	Time interval: injury/operation	Operative findings	Time interval: injury/final state	Motor recovery
3	5 months	Fibrotic lesion in continuity	64 months	Pectoralis major 4
4	4 months	Large detached glioma (avulsion)	75 months	None
6	7 months	Avulsed. Distal stump mingled with glioma of upper trunk	21 months	None
7	3 months	Not identified; probably torn out	53 months	None
10	9 months	In continuity. Scarred	75 months	Triceps 2
20	3 months	Soft lesion in continuity	24 months	None
25	4 months	Hard lesion in continuity	13 months	Pectoralis major 4 Triceps 2
28	3 months	Hard lesion in continuity	3 months	—
29	9 months	Avulsed	9 months	—

TABLE VIII

FINDINGS AT OPERATION. EIGHTH CERVICAL NERVE. EIGHT PATIENTS

Case number	Time interval: injury/operation	Operative findings	Time interval: injury/final state	Motor recovery
3	5 months	Avulsed complete with anterior and posterior roots and posterior root ganglion	64 months	None
6	7 months	Hard lesion in continuity	21 months	None
7	3 months	Hard lesion in continuity	53 months	None
10	9 months	Hard lesion in continuity	75 months	Flexor carpi ulnaris 3
20	3 months	Firm, white, loose	24 months	None
25	4 months	Hard lesion in continuity	13 months	Pectoralis major 4
28	3 months	Probably avulsed	3 months	—
29	9 months	Seen to be torn	9 months	—

of recovery apart from that in the scapular muscles. At the other end of the scale was the finding in one case of an apparently normal plexus. In the presence of a peripheral degenerative lesion such a finding almost certainly means that the damage is intradural and that the outlook is poor—in this case recovery was of grade M.3, S.0. Such a finding may however mislead the surgeon into giving an unwarrantably good prognosis.

The results in the other eleven patients subjected to supraclavicular exploration are set out in Tables VI to IX, in which findings at operation are, where possible, related to eventual motor recovery in the probable distribution of the nerve concerned. The probable motor distribution of the nerves of the brachial plexus is illustrated in Table V. It is possible in nine cases to relate the operative findings in the fifth and sixth cervical nerves to eventual recovery (Table VI). In three cases the nerves were seen to be torn, and in none of these was there effective recovery in their distribution. In one case in which a restricted exposure was used the nerves were thought to be torn, but later recovery was seen in the deltoid and biceps. In the remaining five cases there was a lesion in continuity with fibrosis or with the formation of a neuroma. It does not seem that appearances in such cases give any reliable guide to prognosis. The findings do, however, confirm the clinical impression that the lesion of the fifth and sixth cervical nerves is usually extradural.

In seven cases operative findings in the seventh cervical nerve can be related to recovery (Table VII). In three of these the nerve was certainly or almost certainly avulsed and in none of them did useful recovery occur. In the other four cases, in which the nerve, either soft or fibrotic, was seen to be in continuity, operative findings did not seem to bear particularly on the degree of eventual recovery.

TABLE IX

FINDINGS AT OPERATION. FIRST THORACIC NERVE. SEVEN PATIENTS

Case number	Time interval: injury/operation	Operative findings
3	5 months	Probably avulsed
6	7 months	Pulled out
7	3 months	Hard lesion in continuity
10	9 months	Avulsed, in continuity by meningocele
20	3 months	Soft lesion in continuity
25	4 months	Hard lesion in continuity
28	3 months	Probably avulsed

In five cases operative findings in the eighth cervical nerve can be related to recovery (Table VIII). In one of these the nerve was found to be avulsed together with its anterior and posterior roots. No recovery occurred in its distribution. In another case the nerve was found to be firm, white and rather loose, and it is almost certain that in this case also proximal avulsion had occurred. Twenty-four months after injury no recovery had occurred in its distribution. In the remaining three cases the nerve was found to be in continuity though fibrotic. In one of these there was recovery in the flexor carpi ulnaris.

Operative findings in the first thoracic nerve cannot really be related to recovery, because it is doubtful whether any recovery occurred in its distribution. The findings are however of interest in the general consideration of the pathology of these lesions and possibly also as an indication of the severity of the injury to the rest of the plexus (Table IX). In four cases the nerve was almost certainly avulsed and in three it was in continuity and either soft or fibrotic. In the three cases of avulsion in which the period of observation was twelve months or longer the degree of recovery of the whole plexus was very poor. In only one of the three patients, all of whom have been under observation for twelve months or more, in whom the nerve was found to be in continuity was there useful recovery of the rest of the plexus.

Dr Scarff's findings in the patient on whom he performed cervical laminectomy are specially interesting and significant, and will be considered separately in the section of this paper which deals with axon reflexes.

In general, operation to be really useful must give a good exposure of the plexus. It is only easy to interpret the findings when part or all of the plexus is torn apart or avulsed from the spinal column. The prognosis of lesions in continuity cannot be determined by inspection, nor can inspection help in making the distinction between intradural and extradural lesions in such cases. Two examples of operative findings are illustrated in Figures 7 and 8.

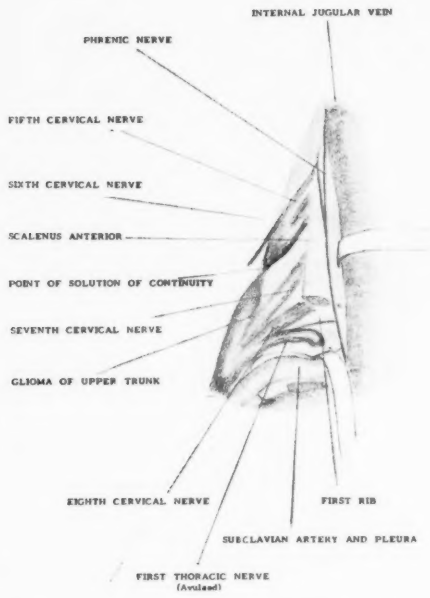

FIG. 7

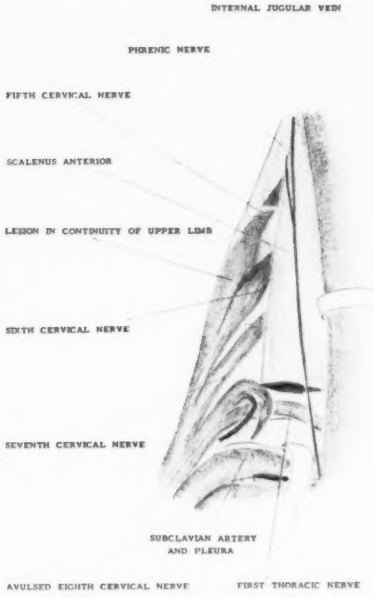

FIG. 8

Figure 7—One of the more common findings at operation in a case of traction lesion of the brachial plexus. The lesion of the upper trunk is one showing actual solution of continuity, the seventh and eighth cervical nerves are in continuity, and the first thoracic nerve has been avulsed. Figure 8—Another type of operative finding in a case of traction lesion of the brachial plexus. The lesion of the upper trunk is one in continuity, with the formation of a large neuroma. The seventh cervical and first thoracic nerves are in continuity, and the eighth cervical nerve has been avulsed.

HISTOLOGICAL FINDINGS

In twelve cases funicular biopsies were taken from one or more of the component nerves of the plexus. By this method only a small part of the nerve is removed, so there are obvious limitations to its use for determining the state of the whole nerve. In addition to this obvious source of error, identification of the nerve was often difficult. Frequently the so-called funicular biopsy consisted only of a piece of fibrous tissue. Table X shows the results for the whole of the plexus. Leaving aside the finding of fibrous tissue only, three findings predominate: 1) fibrous tissue with fine unmyelinated nerve fibres (eight specimens) (Fig. 9); 2) numerous myelinated fibres with normal axons and with little disruption of neural architecture (eight specimens) (Fig. 10); neural structure with complete degeneration of conducting elements (six specimens) (Fig. 11).

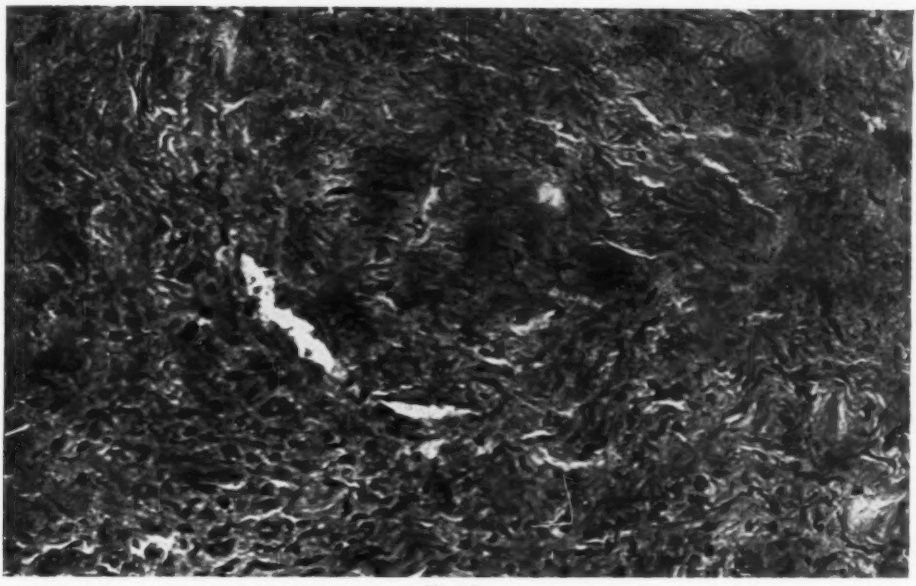

FIG. 9

Histological findings in a funicular biopsy from a case of traction lesion of the brachial plexus. Case 28. Biopsy from eighth cervical nerve. (Glees stain, ×380.) Fibrous tissue with occasional fine unmyelinated fibres. (Dr H. Sissons and Dr C. G. Woods.)

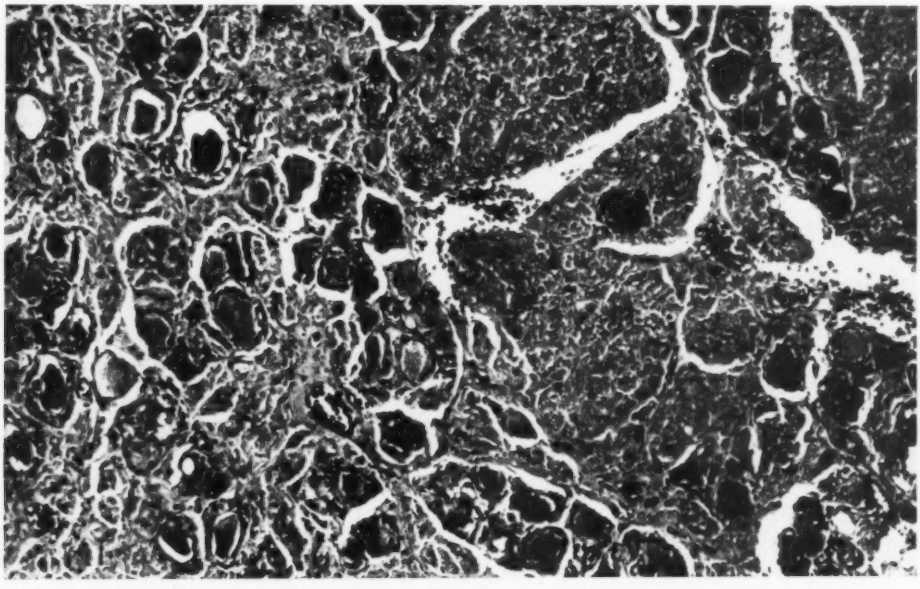

FIG. 10

Histological findings in a funicular biopsy from a case of traction lesion of the brachial plexus. Case 3. Biopsy from eighth cervical nerve. (Lissamine fast red stain, ×160.) Myelinated fibres and ganglion cells. (Dr H. Sissons and Dr C. G. Woods.)

The first finding is difficult to interpret: the fine fibres may represent undamaged axons or they may be the fine fibres of regeneration. This histological picture does not seem to bear any relation to recovery in the distribution of the nerve so affected.

The finding of numerous myelinated fibres with or without ganglion cells is strong evidence that the nerve has been avulsed from the spinal cord. In the event of avulsion of both anterior and posterior roots from the cord, the posterior root is likely to be detached

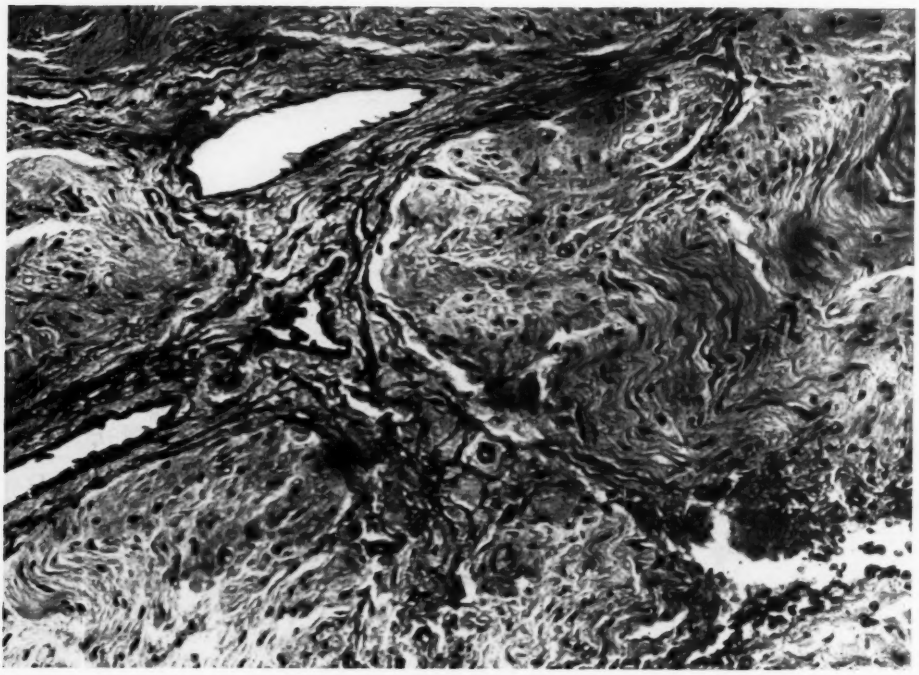

FIG. 11

Histological findings in a funicular biopsy from a case of traction lesion of the brachial plexus. Case 6. Biopsy from eighth cervical nerve. (Lissamine fast red stain, ×320.) Neural structure with degeneration of conducting elements. (Dr H. Sissons and Dr C. G. Woods.)

complete with its ganglion and, as has been shown, that ganglion may be pulled through the intervertebral foramen. Under these circumstances (Fig. 12) the peripheral axons of the cells of the root ganglion remain in continuity with their nutrient cells and so do not undergo degeneration. This appearance is in contrast with that of a lesion outside the theca, in which the axons of the posterior root become separated from their nutrient cells and so undergo degeneration. The presumption is that the finding of numerous myelinated fibres would argue a bad prognosis, certainly for the sensory part of the nerve and—since it is unlikely that the posterior root would be torn away and the anterior root be left intact—probably for the motor part of the nerve also. Numerous myelinated fibres were found in biopsies of eight nerves, once in the fifth and sixth cervical, twice each in the seventh and eighth cervical and three times in the first thoracic. The prognostic significance of the appearances in the first thoracic nerve can probably be discounted, for it is doubtful if any recovery occurred in the distribution of this nerve. There was no recovery in the distribution of the eighth cervical nerves so affected, and there was recovery of triceps to M.R.C. Grade 1 in that of one of the seventh cervical nerves. In the case in which myelinated fibres were found in the fifth and

sixth cervical nerves there was recovery of biceps to M.R.C. Grade 2. The finding of reasonably normal neural architecture with many myelinated fibres can therefore be taken as a fairly reliable indication of avulsion of roots from the cord and as an indication of a bad prognosis.

The third finding—of complete degeneration of conducting elements—is typically the appearance of the distal part of a nerve which has suffered a lesion leading to peripheral degeneration. We cannot gain from it any information about the severity of the lesion beyond

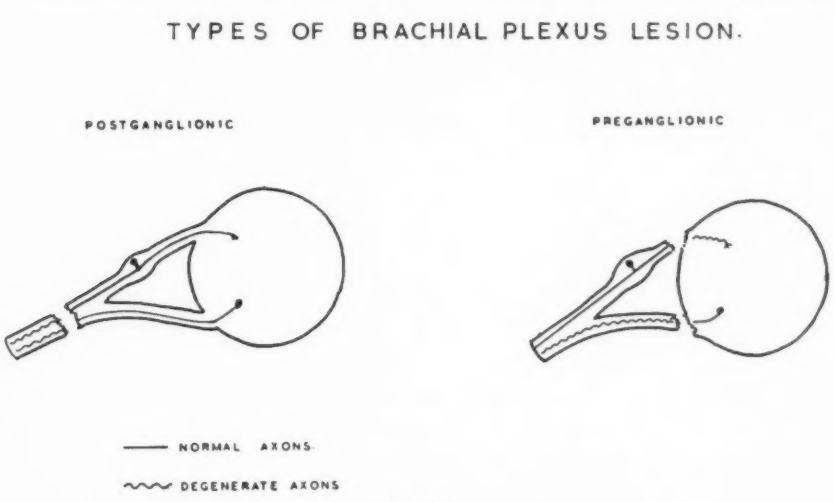

FIG. 12

Diagrammatic illustration of the two types of traction lesion of the brachial plexus. Showing mechanism of axonal degeneration in the postganglionic type, and preservation of axons of the posterior root system in the preganglionic type.

the point that it has been severe enough to have determined degeneration. Nevertheless, the finding is important in showing that the site of the lesion is distal to the posterior root ganglion.

In general, the most important histological finding is that of relatively normal neural structure with many myelinated fibres, as indicating an intradural, preganglionic lesion. Further work is needed to determine the significance of the fine nerve fibres seen in other sections.

EVIDENCE FROM EXAMINATION OF AXON REFLEXES

One of the more useful pieces of evidence to have emerged so far is that which suggests that in a number of cases the lesion of one or more nerves is intradural and preganglionic, and that the frequency of this occurrence determines in part the generally poor prognosis of traction lesions of the brachial plexus. The question is now raised of whether the differentiation between extradural postganglionic and intradural preganglionic lesions can be made by any means other than exploration and biopsy, or for that matter by any other more reliable method. Study of the axon reflexes of the affected limb might be a simple way of making this distinction.

In their studies of the triple response and the cold vasodilation response Lewis and his colleagues (Lewis, Harris and Grant 1927; Lewis and Landis 1930; Lewis 1930; Lewis 1942) concluded that these responses were mediated through an " axon reflex." They postulated the existence of a branched axon of the posterior root system, one branch supplying the skin and the other innervating a subcutaneous vessel. Stimuli applied to the cutaneous branch were supposed to cause vasodilation through a reflex carried proximally in this branch and distally in the vasomotor one. This hypothetical system was shown to be independent of the autonomic network. Its parent axons were shown to be those of the posterior root. Greenfield

TABLE X

HISTOLOGICAL FINDINGS IN FUNICULAR BIOPSIES. TWELVE CASES OF TRACTION INJURY OF THE BRACHIAL PLEXUS

Case number	Time interval: injury/biopsy	Histological findings			
		C.5/6	C.7	C.8	T.1
1	4 months	Normal nerve bundles with many myelinated fibres	Myelinated fibres	—	—
3	5 months	Degeneration of conducting elements. Some axons seen in silver-impregnated sections	Fibrous tissue. Many unmyelinated fibres present	Dorsal root ganglion with myelinated fibres entering and leaving (Fig. 10)	Myelinated nerve. Normal histological structure
4	4 months	Complete degeneration of all conducting elements	Posterior root ganglion. Many myelinated fibres	—	—
6	7 months	Fibrous tissue with occasional slender fibres	Fibrous tissue. A few slender fibres	Empty Schwann tubes (Fig. 11) occasional unmyelinated fibres	Many myelinated fibres. Reasonably normal histological structure
7	3 months	Fibrous tissue	—	Fibrous tissue	Small nerve bundles with intact unmyelinated fibres
10	9 months	Fibrous tissue	A few slender fibres	—	No neural elements
11	8 months	Complete degeneration of all conducting elements	—	—	—
12	6 months	Complete degeneration of all conducting elements	—	—	—
13	7 months	Fibrous tissue with fine unmyelinated fibres	—	—	—
20	3 months	Neural tissue without conducting elements	Neural tissue without conducting elements	Myelinated nerve fibres	Myelinated nerve fibres
25	4 months	—	Neuromatous tissue. Some slender unmyelinated fibres	—	—
28	3 months	Fibrous tissue	Fibrous tissue	A very few fine unmyelinated fibres in fibrous tissue (Fig. 9)	—

and his colleagues (Greenfield *et al.* 1951) have since shown that under certain circumstances cold vasodilation can still occur in the finger after complete denervation and axonal degeneration. Further work too has shown that the axons responsible for the reflex are not necessarily those concerned with conscious sensation (Bonney 1954*b*). Although it is impossible to base the physiological concept of an axon reflex on any definite anatomical knowledge, it is nevertheless certain that when degeneration of cutaneous axons occurs after section of a nerve there is profound modification of those responses known as axon reflexes. A post-ganglionic lesion of one of the nerves of the brachial plexus would thus determine the modification or the disappearance of axon reflexes in the autonomous territory of that nerve. This alteration would become apparent after the lapse of a period of time long enough to determine axonal degeneration—perhaps three to six weeks. In the case of preganglionic

damage, degeneration would not occur in the axons of the posterior root of the nerve so affected. Hence, axon reflexes would continue to be obtainable in the autonomous territory of the nerve. It is clear that this circumstance might offer an agreeable method of distinguishing postganglionic from preganglionic lesions. In a preliminary report (Bonney 1954*a*) it was shown that this was likely to be the case. Since that time the method has been applied to sixteen more patients so that further correlation of results with operative findings and with final recovery has been possible.

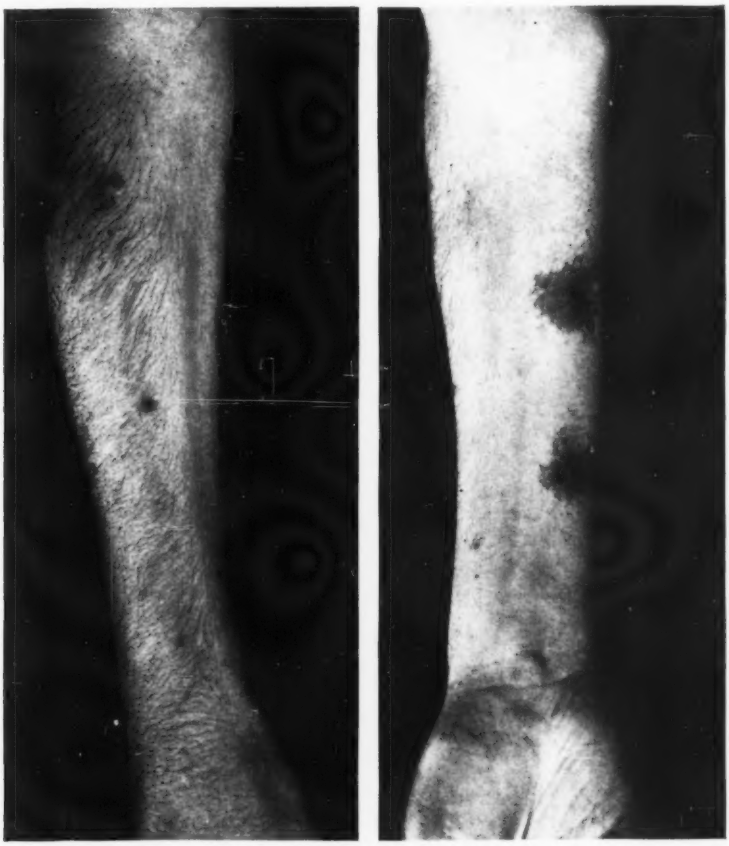

FIG. 13

Histamine responses of forearm in case of traction lesion of the brachial plexus. (Case 6. Injury June 23, 1952. Test January 12, 1953.) Showing positive response on ulnar side of forearm, negative response on radial side. Both areas of skin completely anaesthetic.

Little difficulty was experienced in measuring the response to histamine, which usually was either a clear-cut positive or negative (Fig. 13). In general, the results with the cold vasodilation test were clear-cut (Figs. 14 and 15), the contrast being between an insignificant response and a vasodilation of nearly normal degree. In a few cases the affected fingers showed a very slow vasodilation, generally reaching a maximum well below that of the healthy fingers. In these it was difficult to know whether to classify the response as positive or negative.

A completely arbitrary line was therefore taken: if the final degree of vasodilation was less than half that shown by the corresponding healthy finger the response was classed as negative; if more than half it was classed as positive.

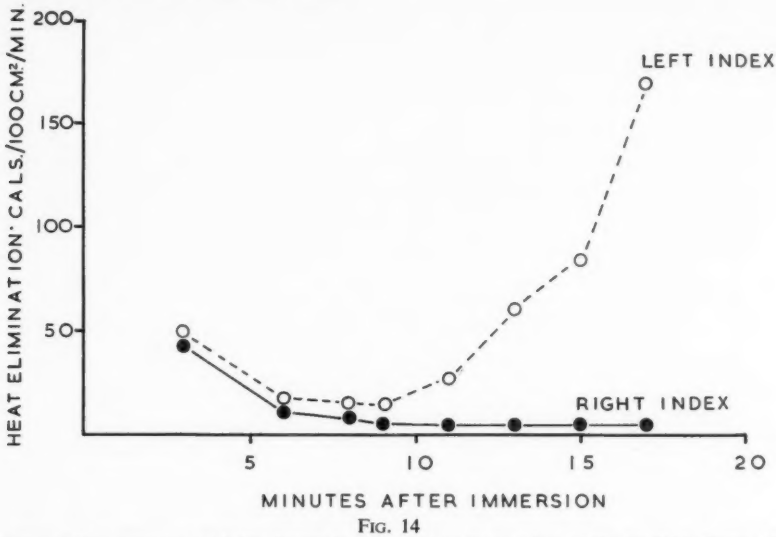

FIG. 14

Cold vasodilation response of index fingers in a case of traction lesion of the brachial plexus (*right*). (Case 25. Injury October 1956. Test January 23, 1957.) Showing absence of response in the right index finger. Indication of postganglionic damage.

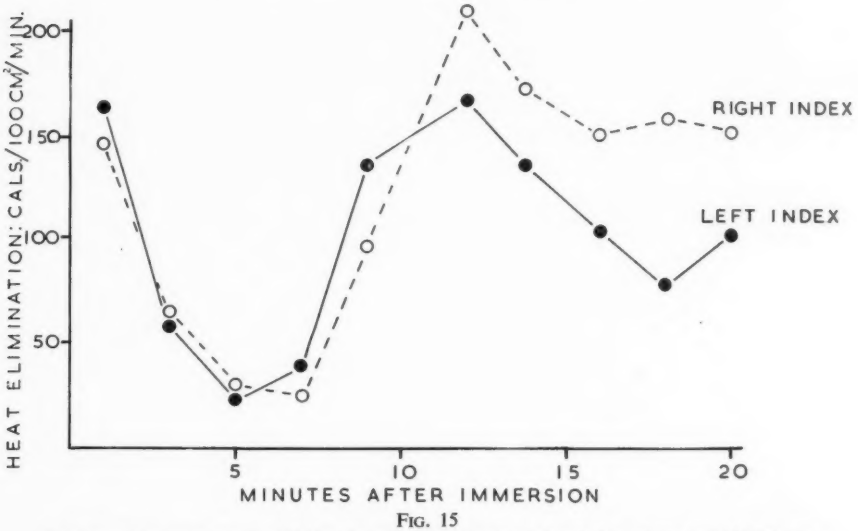

FIG. 15

Cold vasodilation response of index fingers in a case of traction lesion of the brachial plexus (*left*). (Case 3. Injury July 7, 1952. Test October 28, 1952.) Showing response of left index finger almost identical with that of the right index finger. Indication of preganglionic damage.

The complete test was done on twenty-six patients, at intervals of from five weeks to thirty-nine months (average six months) from injury in the case of first testing, and of from thirteen to ninety-three months (average forty-eight months) in the case of the follow-up

examination. Seven different patterns of response were seen at first testing, but two patterns accounted for sixteen cases (Fig. 16). These were: negative responses in all sites (eleven patients), and positive responses in all sites but one (five patients). The follow-up examination afforded the opportunity of testing the persistence of reflex activity after a presumed preganglionic lesion. In eleven cases the histamine responses were retested after intervals of over fifteen months and in eight cases the cold vasodilation responses were similarly retested.

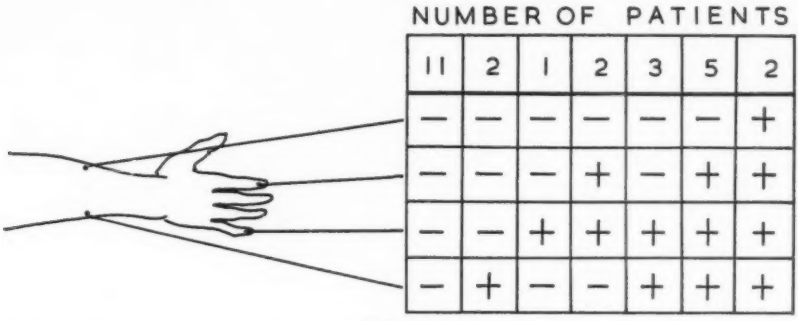

FIG. 16

Patterns of axon reflex response. Twenty-six patients with traction lesions of the brachial plexus in whom the complete test was done. Histamine response on the radial and ulnar sides of the forearm are shown respectively in the top and bottom lines. Cold vasodilation responses of the index and fifth fingers are shown in the middle two lines.

There was complete agreement between the histamine responses tested at intervals of from sixteen to sixty months. As regards the results of the cold vasodilation test, there was divergence in four of the sixteen fingers tested. In each case the divergence was the finding at the second test of a vasodilation response not shown at the first test. This occurred in the absence of recovery of sensation in the fingers. This is not unexpected, since it has been shown (Bonney 1954*b*) that reinforcement of the cold vasodilation response can be produced by regenerating axons which do not conduct sensation to consciousness.

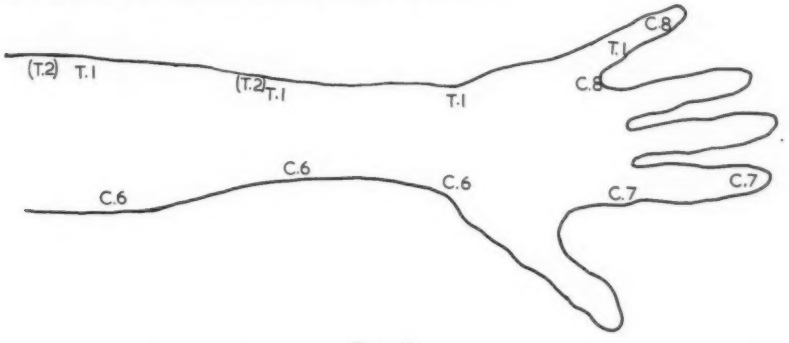

FIG. 17

Cutaneous distribution of the nerves of the brachial plexus (Foerster 1930, Bonney 1954*a*).

Thus, axon reflexes could be elicited in one-third of all the sites tested. In support of the suggestion that this is evidence for a high incidence of preganglionic lesions, this figure may be compared with that of the incidence of the finding of myelinated fibres in biopsy specimens. It is, however, necessary to go further than this and determine whether the type of axon reflex response in a given area can be related to pathological findings in the nerve supplying that area. To do this it is necessary to know the peripheral cutaneous distribution of the

individual cervical nerves. Foerster's (1933) work is the basis of this knowledge, but further evidence (Bonney 1954*a*) suggests that the distribution may be represented as follows (Fig. 17). On this hypothesis the territory of the sixth cervical nerve does not extend on to the index finger, which is supplied from the seventh and eighth cervical nerves. The little finger is supplied from the eighth cervical, and the first thoracic nerve supplies a variable amount of this finger and of the ulnar side of the forearm. On this basis the following correlations are possible in the twenty-six patients who had the complete test. In the case of the fifth and sixth cervical nerves the axon responses can be compared with the clinical findings; with regard to all the nerves of the plexus the axon responses can be compared with findings at operation and with histological appearances.

TABLE XI

SIXTH CERVICAL NERVE. COMPARISON OF AXON RESPONSES WITH FINDINGS AT OPERATION. FIFTEEN PATIENTS

Case number	Histamine response radial forearm	Time interval: injury/test	Time interval: injury/operation	Operative findings
1	Positive	39 months	4 months	Apparently normal
3	Negative	5 months	5 months	Lesion in continuity at lateral border of scalenus anterior
4	Negative	15 months	5 months	Torn at lateral border of scalenus anterior
6	Negative	7 months	7 months	Torn 2 centimetres lateral to scalenus anterior
7	Negative	7 weeks	3 months	Lesion in continuity with large hard neuroma
10	Negative	8 months	8 months	Lesion in continuity at lateral border of scalenus anterior
12	Negative	15 months	6 months	Torn at lateral border of scalenus anterior
13	Negative	7 months	7 months	Avulsion. Glioma of upper trunk lateral to scalenus anterior
18	Negative	4 months	Hours (primary operation)	Torn
20	Negative	3 months	3 months	Grey, attenuated, soft, in continuity
24	Negative	6 months	11 months	Avulsion—absent
25	Negative	3 months	4 months	In continuity. Fibrotic
26	Negative	3 months	5 months	Avulsion—absent
28	Negative	3 months	3 months	Lesion in continuity with neuroma
29	Negative	7 months	9 months	In continuity—thickened

In all but two cases the histamine response on the radial side of the forearm was negative. As has been shown previously, the clinical evidence strongly suggests that in the majority of cases the lesion of the sixth cervical nerve was postganglionic.

Comparison of axon responses with operative findings—The comparison of axon responses with findings at operation is possible in fifteen cases. Regarding the sixth cervical nerve (Table XI), the predominantly negative reflex findings were associated in all cases with a demonstrably postganglionic lesion. In seven of these fifteen cases there was a demonstrable solution of continuity—either a tear-apart or an avulsion. In the case of the seventh cervical nerve (Table XII) three of the four positive reflex findings were associated with the finding of a nerve in continuity. In the fourth, the nerve was found avulsed complete with its roots and posterior root ganglion. In six of the ten instances of negative reflex findings the nerve was evidently avulsed or torn apart, in one probably avulsed and in the three others in

TABLE XII

SEVENTH CERVICAL NERVE: COMPARISON OF AXON RESPONSES WITH FINDINGS AT OPERATION. FOURTEEN PATIENTS

Case number	Cold vasodilation response: index finger	Time interval: injury/test	Time interval: injury/operation	Operative findings
1	Positive	39 months	4 months	Apparently normal
3	Positive	5 months	5 months	In continuity. Thickened and fibrotic
4	Positive	15 months	4 months	Found avulsed with root ganglion
6	Negative	7 months	7 months	Found avulsed
7	Negative	7 weeks	3 months	Not identified. Probably avulsed
10	Negative	8 months	8 months	In continuity. Fibrotic
13	Negative	7 months	7 months	Absent. Avulsed
18	Negative	4 months	Hours (primary operation)	Torn
20	Negative	3 months	3 months	Grey, attenuated, soft—in continuity
24	Negative	6 months	11 months	Absent. Avulsed
25	Negative	3 months	4 months	In continuity. Fibrotic
26	Negative	3 months	5 months	Absent. Avulsed
28	Positive	3 months	3 months	In continuity. Fibrotic
29	Negative	7 months	9 months	Absent. Avulsed

TABLE XIII

EIGHTH CERVICAL NERVE. COMPARISON OF AXON RESPONSES WITH FINDINGS AT OPERATION. ELEVEN PATIENTS

Case number	Cold vasodilation response: little finger	Time interval: injury/test	Time interval: injury/operation	Operative findings
3	Positive	5 months	5 months	Avulsed with posterior root ganglion
6	Positive	7 months	7 months	In continuity. Fibrotic
7	Positive	7 weeks	3 months	In continuity. Fibrotic
13	Negative	7 months	7 months	Absent. Avulsed
18	Negative	4 months	Hours (primary operation)	Torn
20	Positive	3 months	3 months	Firm, white, loose
24	Negative	6 months	11 months	Absent. Avulsed
25	Negative	3 months	4 months	In continuity. Fibrotic
26	Negative	3 months	5 months	Absent. Avulsed
28	Positive	3 months	3 months	Found: probably pulled out
29	Negative	7 months	9 months	Torn

TABLE XIV

FIRST THORACIC NERVE. COMPARISON OF AXON RESPONSES WITH FINDINGS AT OPERATION. ELEVEN PATIENTS

Case number	Histamine response ulnar forearm	Time interval: injury/test	Time interval: injury/operation	Operative findings
3	Negative	5 months	5 months	Found. Probably avulsed
6	Positive	7 months	7 months	Found avulsed from I–V foramen
7	Positive	7 weeks	3 months	In continuity. Fibrotic
10	Negative	8 months	8 months	Found pulled out, connected by meningocele
13	Negative	7 months	7 months	Absent. Avulsed
18	Negative	4 months	Hours (primary operation)	Seen to be in continuity
20	Positive	3 months	3 months	Grey, attenuated, soft
24	Negative	6 months	11 months	Absent. Avulsed
26	Negative	3 months	5 months	Absent. Avulsed
28	Positive	3 months	3 months	Probably avulsed
29	Negative	7 months	9 months	Torn

continuity. In the case of the eighth cervical nerve (Table XIII) there were five positive findings. Twice the nerve was found to be in continuity and three times it was found to be pulled out—in one of these cases complete with its posterior root ganglion. Five negative findings were associated with avulsion or tear-apart and one with a finding of a lesion in continuity. In the

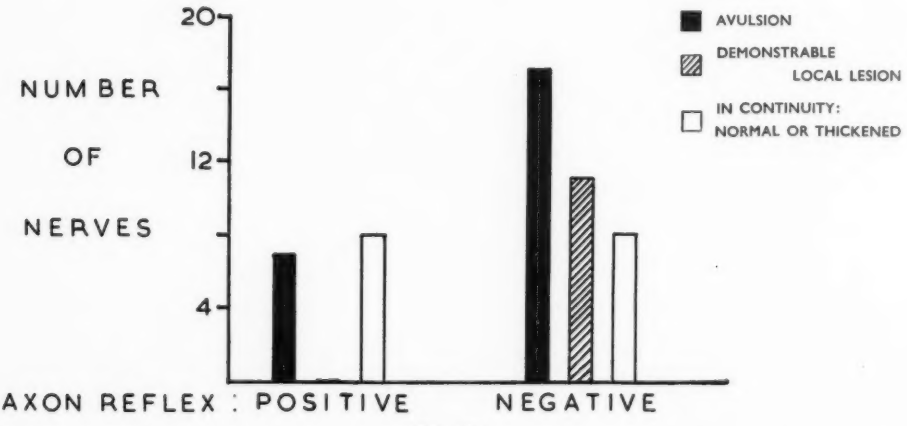

FIG. 18

Axon responses related to findings at operation. On the basis of the distribution illustrated in Figure 17, findings at operation have been related to axon responses in the territories of the several nerves of the plexus.

case of the first thoracic nerve (Table XIV) there were four positive and seven negative axon responses. In two of the cases of positive response the nerve was found to be avulsed and in two to be in continuity. Six of the seven negative responses were associated with avulsion or tear-apart of the nerve.

Negative reflex findings, then, are predominantly associated with the finding of a demonstrable lesion in continuity or of complete avulsion. Positive reflex findings may be associated with appearances ranging from that of a normal nerve to avulsion of a nerve complete with its roots and posterior root ganglion. There is evidently a greater chance of interpreting the operative findings in the case of negative axon responses (Fig. 18).

Comparison of axon responses with histological findings—The axon responses can now be compared with the histological findings in the eleven cases in which biopsies were taken and in which the complete pattern of axon responses was obtained. In interpreting these findings

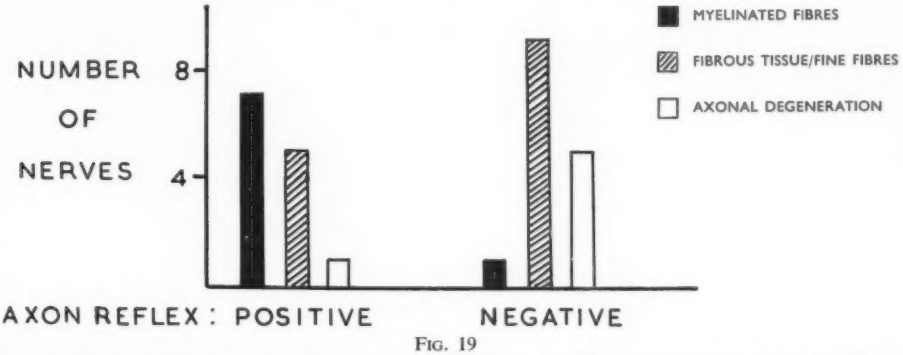

FIG. 19

Axon responses related to histological findings. On the basis of the distribution illustrated in Figure 17, histological findings have been related to axon responses in the territories of the several nerves of the plexus.

it is necessary to allow for inaccuracies caused by difficulty of identification at operation, difficulty in taking the funicular biopsy and individual variation in the distribution of the nerves. To summarise the information contained in Table XV: thirteen positive reflex findings were associated in seven instances with the histological appearance of myelinated fibres in the nerve presumed to supply the area of skin concerned. On the other hand, the fifteen negative findings were associated in only one instance with the appearance of myelinated fibres. It seems that within fairly wide limits the theory of the distribution of the nerves is tenable. It is also likely that positive axon responses in a certain distribution can be linked with the finding of myelinated fibres in a given nerve (Fig. 19).

Further evidence in support of this idea is provided by operative, physiological and histological studies in four cases.

Operative evidence—I am indebted to Dr John E. Scarff of the Presbyterian Hospital, New York, for permission to publish his findings in the first case.

Case 19—A man aged twenty was injured in a motor cycle accident on November 2, 1955. He sustained a complete supraclavicular traction lesion of the right brachial plexus with a right Horner's syndrome. Pain was initially severe and remained so. The patient was seen at the Royal National Orthopaedic Hospital on December 14, 1955, when he showed motor paralysis of the right upper limb sparing only the trapezius and rhomboids, and complete sensory paralysis. Axon reflex responses were tested on that date: there was a negative response to histamine on the radial side of the forearm but the cold vasodilation response of the index and fifth fingers and the response to histamine on the ulnar side of the forearm were positive. On this evidence, a diagnosis of a postganglionic lesion of the fifth and sixth cervical nerves and a preganglionic lesion of the seventh and eighth cervical and of the first thoracic nerves was made. It was thought likely that there had been extensive avulsion of roots from the cord. In April 1956 the patient consulted Dr John E. Scarff at the Neurological Institute of the Presbyterian Hospital, New York. At that time the clinical state was unchanged. Cervical hemilaminectomy was performed by Dr Scarff on May 10, 1956. The findings were as follows. The fifth cervical nerve appeared slightly smaller than usual and rather more relaxed than usual. Electrical stimulation of the root produced prompt but not very vigorous movements of axial

TABLE XV

COMPARISON OF AXON RESPONSES WITH HISTOLOGICAL FINDINGS

Case number	Time interval: injury/test	Time interval: injury/operation	Histamine response radial forearm	Histology C.6	Cold vasodilation response: index finger
1	39 months	4 months	Positive	Myelinated nerve fibres	Positive
3	5 months	5 months	Negative	Degeneration of all conducting elements	Positive
4	15 months	4 months	Negative	Degeneration of all conducting elements	Positive
6	7 months	7 months	Negative	Fibrous tissue. Occasional slender nerve fibre	Negative
7	7 weeks	3 months	Negative	Fibrous tissue	—
10	8 months	8 months	Negative	Fibrous tissue	Negative
12	15 months	6 months	Negative	Degeneration of conducting elements	—
13	7 months	7 months	Negative	Fibrous tissue with many fine nerve fibres	—
20	3 months	3 months	Negative	Degeneration of conducting elements	Negative
28	3 months	3 months	Negative	Fibrous tissue	Positive
29	3 months	4 months	—	—	Negative

musculature and possibly of some of the suspensory muscles of the upper limb girdle, but no contraction of the deltoid or of the biceps.

The sixth cervical nerve still held its arachnoid sheath, and running in the arachnoid sheath were very fine nerve fibrils, all of which appeared to be arising from the dorsal root. Stimulation did not produce any detectable motor response.

The seventh cervical nerve had been completely avulsed from the cord. The subarachnoid root sheath was seen to pass out through an oval foramen in the dura, but no nerve components were seen in this subarachnoid sheath when it was opened. The sheath communicated freely with a large extradural meningocele.

The eighth cervical and first thoracic nerves were both completely avulsed from the cord and had been pulled entirely out of the vertebral canal.

The findings at operation were thus in complete agreement with the idea of the lesion that had been formulated by clinical examination and by study of the axon reflexes.

Physiological evidence—It has been possible in one case of traction lesion of the plexus (Bonney and Gilliatt 1958) to show that the finding of positive axon responses can be linked with the demonstration of afferent volleys in the intact peripheral axons (Case 23). Although the potentials on the affected side were slightly smaller than those from the opposite arm, their latency was not significantly increased. In a second case (Case 29), in which axon reflexes could not be elicited, it was not possible to demonstrate afferent volleys in the nerves of the affected arm. The physiological evidence thus supports the idea that the finding of positive axon responses indicates functional peripheral axons detached from the central nervous system. In contrast, the finding of negative responses indicates degeneration of conducting elements.

TABLE XV—*continued*

Histology C.7	Cold vasodilation response: little finger	Histology C.8	Histamine response ulnar forearm	Histology T.1
Myelinated nerve fibres	—	—	—	—
Fibrous tissue with many fine nerve fibres	Positive	Posterior root ganglion: many myelinated nerve fibres	Negative	Many myelinated nerve fibres
Posterior root ganglion: many myelinated nerve fibres	—	—	—	—
Fibrous tissue. A few fine nerve fibres	Positive	Degeneration of conducting elements	Positive	Many myelinated nerve fibres
—	Positive	Fibrous tissue	Positive	Small nerve bundles with many intact unmyelinated nerve fibres
Fibrous tissue. A few fine nerve fibres	—	—	Negative	No neural elements
—	—	—	—	—
—	—	—	—	—
Degeneration of all conducting elements	Positive	Numerous myelinated nerve fibres	Positive	Many myelinated nerve fibres
Neuromatous tissue. Some slender unmyelinated fibres	Positive	Fibrous tissue. A few fine nerve fibres	—	—
Fibrous tissue.	—	—	—	—

Histological evidence—In the following case the finding of positive axon responses was associated with the finding in the nerve trunks of numerous myelinated fibres and the finding of nerve fibres in the skin.

Case 27—A man aged twenty was injured in a motor cycle accident on June 7, 1957. He sustained a complete supraclavicular traction lesion of the left brachial plexus with a left Horner's syndrome. Pain was initially severe, but decreased in intensity over the succeeding months. He was seen at the Royal National Orthopaedic Hospital on October 2, 1957, when he showed motor paralysis of the left upper limb with sparing of the trapezius, rhomboids and serratus anterior, and complete sensory paralysis. Axon reflex responses were tested on that date: the response to histamine on the radial side of the forearm was negative, but the cold vasodilation response of the index and little fingers and the response to histamine on the ulnar side of the forearm were positive. On this basis a diagnosis was made of a postganglionic lesion of the fifth and sixth cervical nerves and a preganglionic lesion of the seventh and eighth cervical and of the first thoracic nerves.

Amputation of the arm having been decided on, it was decided to use the opportunity to study the cutaneous innervation of the limb by vital staining with methylene blue. The method used was somewhat similar to that described by Weddell (1941). Above-elbow amputation and injection of the limb were performed on December 19, 1957, by Mr M. S. Brett. The technique of injection was as follows: forty-five minutes after operation 300 millilitres of a 0·03 per cent solution of standard methylene blue stain (British Drug Houses) were injected into the brachial artery of the detached limb, the larger efferent veins having been clamped. A further 100 millilitres of the dye solution were subsequently injected into the radial artery in order to get better staining of the digits. Portions of skin were then taken from the ulnar and radial aspects of the forearm, and from the pads of the index and fifth fingers. Pieces were taken from the ulnar, median and radial nerves at the elbow and from the median nerve at the wrist. All these specimens of skin and nerve were placed in an 8 per cent solution of ammonium molybdate in which they were allowed to remain for twenty-four hours.

They were then washed, dehydrated and cleared. Sections of skin were cut and examined without further staining. Sections of the nerves were cut and stained by the ordinary methods. Nerve fibres could be demonstrated in all areas of skin showing positive axon responses. They were absent from the skin in which the axon responses were negative. Sections from the nerves showed some loss of nerve fibres, but in all numerous intact myelinated fibres were present (Fig. 20).

There is then, overwhelming evidence that the demonstration of positive axon reflexes in a certain area of skin means that the nerve supplying that area of skin has suffered preganglionic damage.

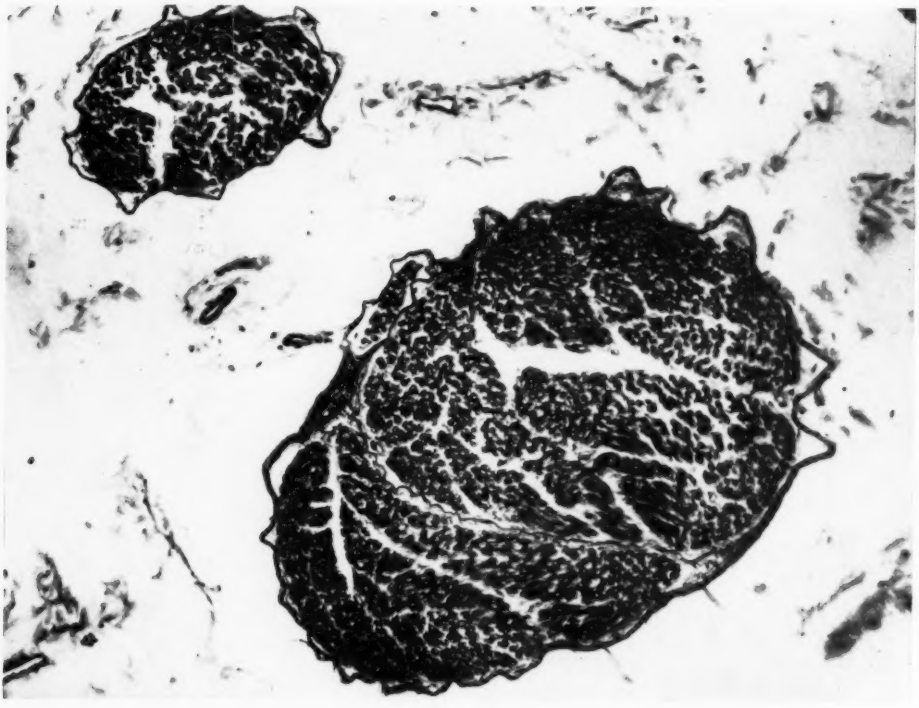

FIG. 20

Transverse section of median nerve in a case of traction lesion of the brachial plexus. (Case 27. Injury June 7, 1957. Amputation December 1957. Lissamine fast red, ×160.) Showing many myelinated fibres. (Dr H. Sissons and Dr C. G. Woods.)

Prognostic significance of axon responses—It is now necessary to inquire into the prognostic significance of the pattern of axon responses. Three aspects of this require consideration. Firstly, the finding of a positive axon response and the inference of a preganglionic lesion would argue a grave prognosis for the sensory part of the nerve concerned and by further inference for the whole nerve. Secondly, the diagnosis of a preganglionic lesion of two or more nerves might signify a great severity of injury and consequently a bad prognosis for the whole plexus. Thirdly, the absence of axon reflexes, while signifying a postganglionic lesion, would give no indication of the severity of the lesion beyond the point that it was a degenerative one. However, given the knowledge that the lesion was a postganglionic one, it would be possible in a good proportion of cases to make a definite diagnosis by exploration. The finding of avulsion or of disruption would settle the question of prognosis.

Consideration of the first aspect—the relation of recovery to axon reflex findings in a given area—is made specially difficult by the fact of the generally low level of sensory recovery. It was decided therefore arbitrarily to take recovery of certain muscles as an indication of recovery in the nerve mainly supplying those muscles. Thus, recovery of biceps was taken

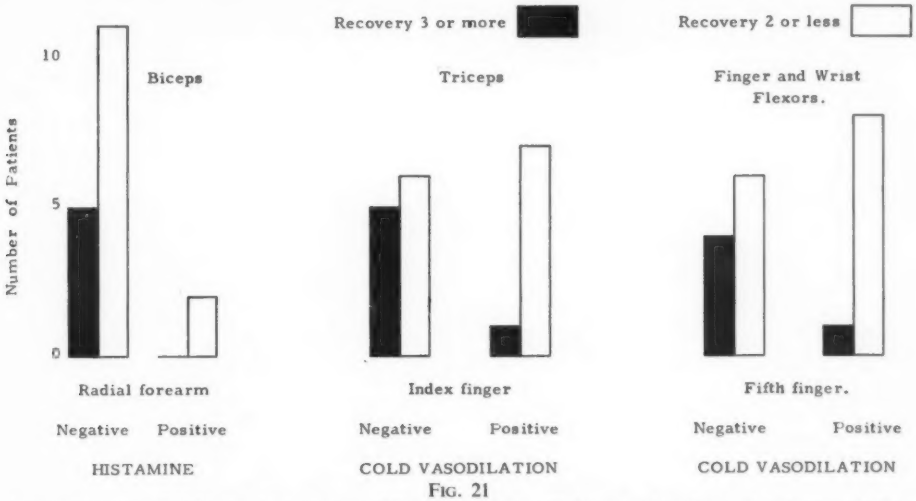

FIG. 21

Axon responses related to motor recovery. Nineteen patients. Eighteen under observation for twenty-four months or more. Prognosis confirmed by laminectomy in the nineteenth.

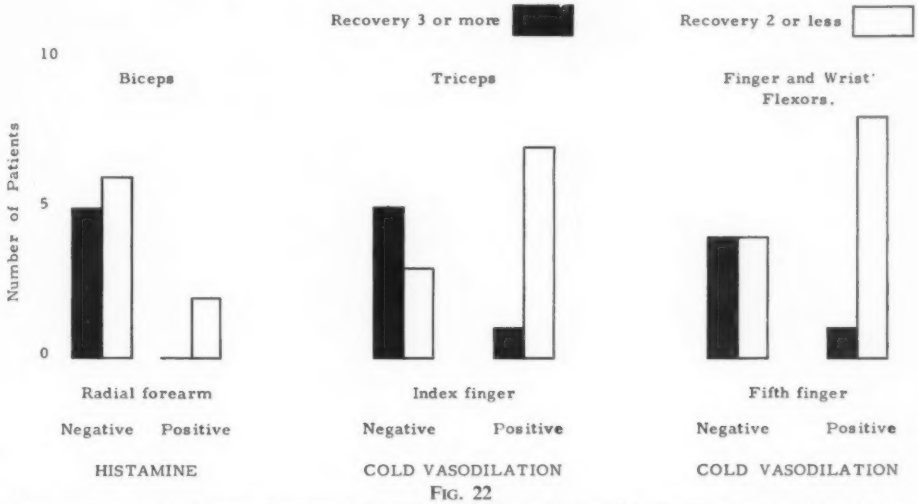

FIG. 22

Axon responses related to motor recovery. Material as in Figure 21, but with those cases excluded in which at operation a clearly irrecoverable postganglionic lesion was found.

as an indication of recovery of the sixth cervical nerve, of triceps as a measure of the seventh, and of the flexors of the wrist and fingers as a measure of recovery in the eighth cervical nerve (Fig. 21). The figures are suggestive but lack significance on account of the frequent failure of recovery with negative axon reflexes. They illustrate the point that, whereas positive

axon responses indicate damage so placed that recovery is very unlikely to occur, negative responses, indicating damage in a site where recovery is possible, give no indication of the severity of the lesion. We are justified in re-examining the results of Figure 21 with those cases excluded in which negative axon responses indicated a postganglionic lesion and in

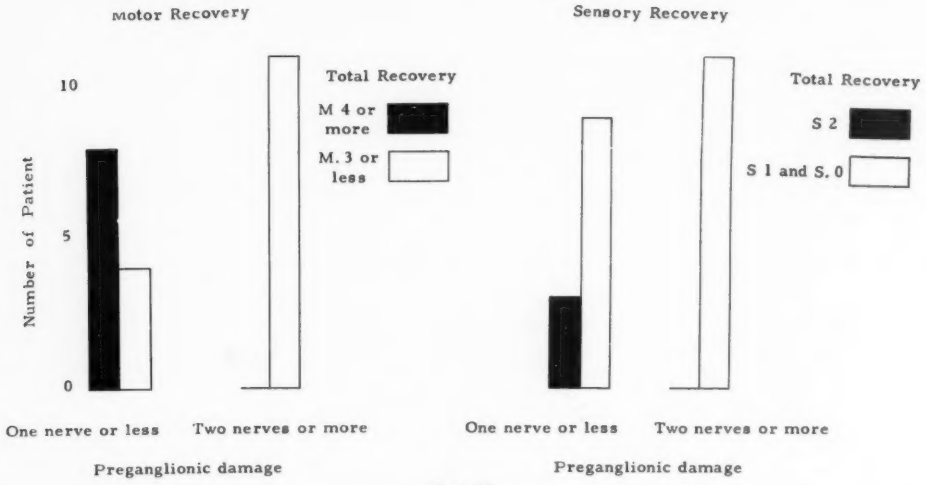

FIG. 23

Total recovery related to incidence of preganglionic damage. Periods of observation at least twelve months.

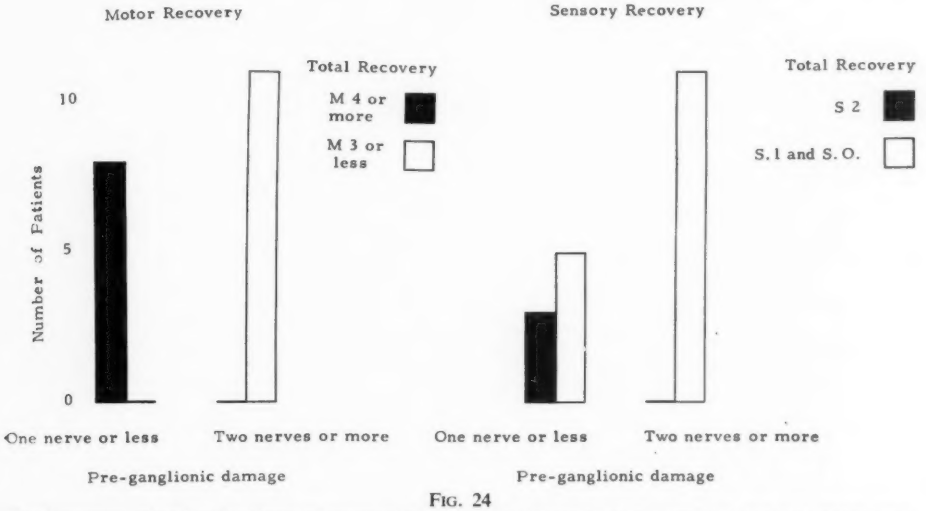

FIG. 24

Total recovery related to incidence of preganglionic damage. Material as in Figure 23, but with those cases excluded in which at operation a clearly irrecoverable postganglionic lesion was found.

which at operation a clearly irrecoverable postganglionic lesion was found (Fig. 22). The figures strongly suggest that if in suitable cases we assess by exploration the prognosis of a known postganglionic lesion, we shall in the remaining cases be able to gain from the axon responses some idea of the prognosis for a given nerve.

Next to be considered is the relation between recovery of the lesion of the plexus as a whole and the number of nerves found to have suffered preganglionic damage. Figure 23 compares the results in two groups: one group with preganglionic damage to no more than one nerve; the other group with two or more nerves so affected. The results are very suggestive in the case of motor recovery; less so of course in the case of recovery of sensibility. If here too we exclude those cases in which negative axon responses indicated a postganglionic lesion and in which at operation a clearly irrecoverable postganglionic lesion of the whole plexus was found, the figures become even more suggestive (Fig. 24). It seems that the finding of a preganglionic lesion of two or more nerves is an indication of a bad prognosis for the whole of the plexus. It seems too that if predominantly negative axon responses indicate a largely postganglionic lesion, the severity of this can quite often be estimated by exploration. In the remaining cases a fairly accurate assessment of prognosis can be made on the result of the axon responses.

As regards the third aspect—the significance of negative axon responses with regard to recovery in the distribution of the relevant nerve—the evidence presented shows that this finding is an indication only of the site of the lesion and that it has no significance with regard to the severity of the lesion.

DISCUSSION

It is clear that the prognosis of a lesion of the brachial plexus is determined by the severity and by the site of the damage and that in certain cases the site of the lesion may determine its severity. The two factors chiefly responsible for the generally poor prognosis of these lesions are the tearing apart of nerves distal to the intervertebral foramina and the avulsion of roots from the spinal cord. Some indication of the severity of the lesion can be given by certain clinical features, notably by the severity of pain and by the presence of a Horner's syndrome. If exploration is applied to all cases as a method of determining prognosis, a large proportion of doubtful results will be obtained. Only if exploration is applied just to those cases in which the lesion is largely postganglionic will a useful proportion of definite results be obtained. Clinical evidence of the site of lesion is obtainable only in the case of the fifth and sixth cervical nerves, so that any other method of placing the lesion of the other nerves is clearly of considerable value.

Examination of axon responses is a simple method and one which gives clear-cut results. Its reliability as a means of determining the site of the lesion requires consideration. The evidence presented here strongly supports the idea that the finding of normal axon responses in an area of skin of a limb affected by a degenerative lesion of the brachial plexus, after time has been allowed for axonal degeneration, means that the lesion of the nerve supplying that area is proximal to the posterior root ganglion. Absence of axon reflexes under similar circumstances means that there is a lesion distal to the posterior root ganglion; there may of course be an associated lesion proximal to the ganglion, but the presence or absence of such a lesion will not affect the result of the test. The evidence connecting the axon responses in a certain area with the lesion in a certain nerve is not quite so good. However, allowing for individual variation, it seems correct to assign the radial side of the forearm to the sixth, the index finger to the seventh and the little finger to the eighth cervical nerves. The ulnar side of the forearm may be assigned to the first thoracic nerve, though in some instances the territory of this nerve does not extend above the level of the wrist. It is thus possible within certain limits to determine from the study of axon responses the sites of injury of the individual nerves.

Theoretically, a lesion placed proximally to the posterior root ganglion is likely to be one of bad prognosis, for the chances are that it will be intrathecal and that the unprotected nerve roots will be torn apart or avulsed from the cord. The evidence presented here bears out this theory and permits the statement that the finding of positive axon responses in a certain area indicates a bad prognosis for the nerve supplying that area of skin. Further, the

prognosis for the lesion of the plexus as a whole seems to be related to the number of roots damaged proximal to their ganglia. In cases where a preganglionic lesion of two or more roots is found, little additional information is to be obtained from operative exploration. This is so because the findings are difficult to interpret and because a bad prognosis can be given irrespective of the results of exploration.

The finding of negative responses in a certain area can be variously interpreted. The only conclusion that we can draw from the isolated observation is that there has been a postganglionic degenerative lesion of the nerve supplying that area of skin. This lesion may be one in continuity or it may be a tear-apart of the nerve. It may be an isolated lesion or it may be associated with avulsion of roots from the cord. For full interpretation the finding requires support from observations at operation and from consideration of the pattern of reflex responses in the arm as a whole. When the damage is predominantly postganglionic, exploration will very often be of value. On the one hand avulsion or tear-apart may be seen and will indicate a hopeless prognosis, and on the other hand the finding of lesion in continuity will indicate the possibility of recovery. It appears too that when a postganglionic lesion of one nerve is associated with a preganglionic lesion of two or more of the other nerves, the likelihood is that there has been severe damage to the former.

On the basis of this study the following plan for the management of a case of complete traction lesion of the brachial plexus is suggested. Examination and accurate testing of motor power and sensibility are done as soon as possible after the injury. Special note is made of the nature of the injury, of the presence of a Horner's syndrome and of the amount of pain. At some time about three weeks after injury the electrical reactions of the muscles are tested in order to confirm that the lesion is in fact a degenerative one. At six to eight weeks motor power and sensibility are again tested and the axon responses are examined. At this stage it will be possible to make with some accuracy the diagnosis of a complete degenerative lesion of the whole plexus and to know the site of injury of the several nerves. Should all or all but one of the nerves have suffered a postganglionic lesion, exploration is indicated to determine whether there has been a tear-apart. If this is found to be the case, then reconstruction can be undertaken without delay; if the nerves are found to be in continuity then it is justifiable to continue with conservative treatment for at least two years in the hope that useful recovery will occur. In the case of a preganglionic lesion of two or more nerves, then the outlook is sufficiently bad to make it justifiable to advise the patient that he is unlikely to regain useful function of the affected limb. He can get on straight away with re-education of the other limb and appliances can be fitted to the affected limb to make it possible for the patient to live with it. There is obviously no urgency about amputation, but if the patient, with full knowledge of what can be done for him in the way of fitting of a prosthesis, opts for it, then it is a justifiable procedure.

SUMMARY

1. Twenty-nine patients with traction lesions of the brachial plexus have been studied.
2. The methods of study have been by clinical examination, by operative exploration and biopsy and by examination of axon reflexes.
3. Results in each of these sections have been related to the progress of the lesions.
4. The results suggest: *a*) that the reason for the generally poor prognosis in traction lesions of the brachial plexus is the frequency of intradural preganglionic damage and of tearing apart of the plexus; *b*) that the former occurrence can with some accuracy be diagnosed by examination of axon reflexes and that the latter can be detected at operation.
5. Indications for operative exploration are given and a plan is outlined for the management of these cases.

It gives me great pleasure to record my thanks to Mr H. J. Seddon for giving me the opportunity to examine these patients and to operate on a number of them, and for the help, advice and encouragement which he has given throughout this work. I wish to thank too Mrs Glen Haig and her staff in the Records Department of

the Royal National Orthopaedic Hospital for their help in tracing patients and with the documentation, Drs H. Sissons, M. Catto and C. G. Woods for the histological work and photomicrography, and Mr R. J. Whitley and his staff in the Photographic Department of the Institute of Orthopaedics for the photographic work. I am much indebted too to Dr R. W. Gilliatt for making it possible to study afferent nerve impulses in two patients, and to Dr John E. Scarff for his most important contribution on the operative findings in one case. Lastly I would like to thank my colleagues Mr Donal Brooks and Mr Martin Brett for the help I have received from them.

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PECTORAL TRANSPLANTATION FOR PARALYSIS OF THE FLEXORS OF THE ELBOW

A New Technique

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Restoration of elbow flexion in paralytic disorders has taxed the ingenuity of surgeons for half a century. Four types of operation have emerged: 1) proximal transplantation of the flexor or extensor origins of the forearm muscles, or both; 2) transplantation of triceps to biceps; 3) transplantation of pectoralis major to biceps; and 4) transplantation of sternomastoid to biceps.

This communication is concerned solely with pectoral transplantation. The first such operation was described in 1917; Schulze-Berge transplanted the tendon of insertion of pectoralis major direct into the belly of biceps. Various modifications of this technique were later employed by Hohmann (1918), Rivarola (1928), Fritz Lange (1930) and Max Lange (1951). These authors were dissatisfied with the original method of insertion of pectoralis major into biceps and used fascia lata or strands of silk to form tendons of insertion either into the biceps tendon or into the ulna. It was not until after 1946 that the ingenious pectoral transplantation described by Clark came into general use. Clark's operation differs fundamentally from those previously described. The lower fibres, comprising the sternal origin of the muscle, are detached from the chest wall and mobilised towards the axilla as far as the nerve and blood supply will allow. The muscle mass is then passed down the arm and attached to the biceps tendon. This operation is particularly useful for patients who have suffered a traction lesion of the upper trunk of the brachial plexus because the sternal head of pectoralis major is not paralysed.

In 1952 one of us (D. M. B.) was confronted with an awkward problem. A girl of ten years was left with extensive paralysis of the upper limb after an attack of poliomyelitis. The distribution of the paralysis was such that neither Steindler's operation nor a triceps transplantation was possible. The clavicular head of pectoralis major, however, contracted strongly and caused the head of the humerus to luxate anteriorly; the sternal head was completely paralysed. At first sight it appeared a good opportunity to carry out one of the earlier techniques of pectoral transplantation. Unfortunately, the fascia lata had been removed previously for a reconstructive procedure on the shoulder. To overcome this difficulty the long head of biceps was converted into a " tendon " by the technique to be described.

THE CONVERSION OF DENERVATED MUSCLE INTO TENDON

At this time we were interested in the changes occurring in muscle as a consequence of ischaemia. One of these changes, due to subtotal ischaemia, is an intense fibrosis which converts muscle into something resembling tendon. We wondered whether this usually noxious change could be put to good use where, as in the transplantation under consideration, a completely fibrotic biceps was likely to be more useful mechanically than a denervated muscle that might stretch under the action of the pectoral transplant. It was surgically feasible to devascularise the long head of biceps; but would denervated muscle respond in the same way as normal muscle? Denervated muscle always becomes more or less fibrous and it therefore seemed reasonable to attempt to hasten the process by deliberately reducing its blood supply.

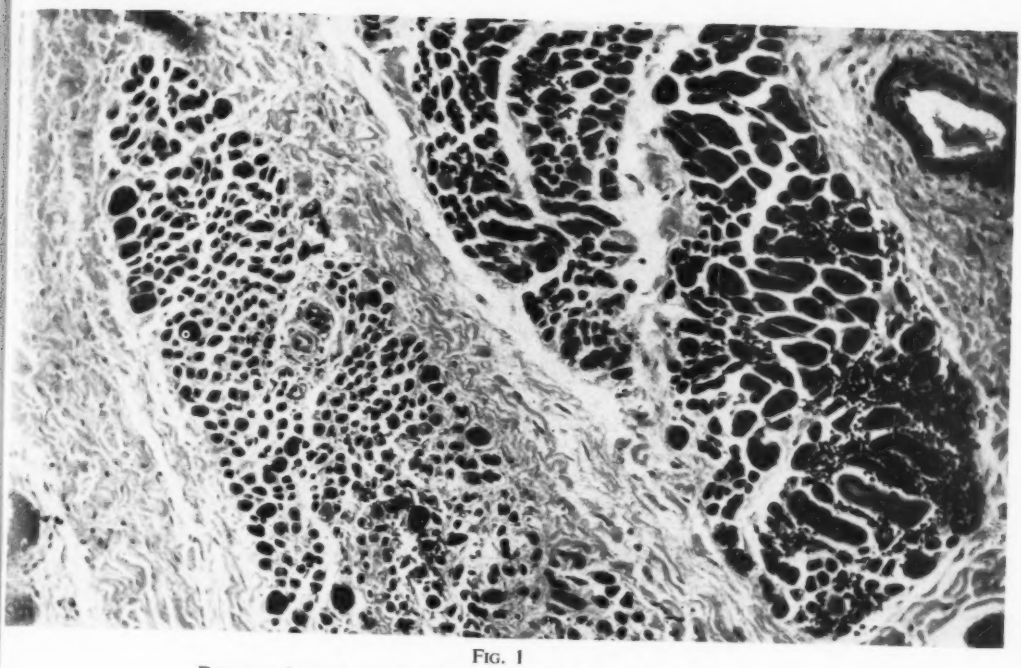

FIG. 1
Denervated muscle two months after surgical devascularisation. (×130.)

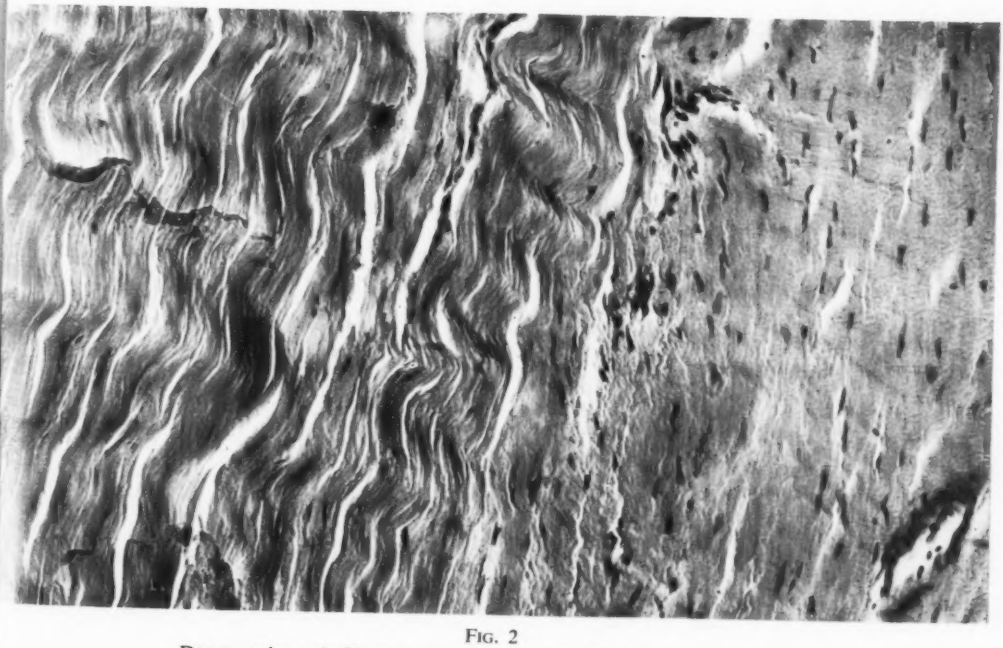

FIG. 2
Denervated muscle fifteen months after surgical devascularisation. (×205.)

If the long head of the biceps is detached from its origin and completely mobilised, it must depend for its blood supply on vessels in its tendon of insertion, although later it may be partly revascularised from its tissue bed. We have found that this blood supply is sufficient to prevent necrosis of the muscle but induces its conversion into what amounts to tendon. It has twice been possible to examine the devascularised long head of biceps, at two and fifteen months from the time of operation. In the tissue removed at two months, Dr H. A. Sissons found no muscle fibres that were necrotic, but most showed advanced atrophy and there was pronounced fibrosis of the muscle; a few muscle fibres of normal size remained. The biopsy material removed at fifteen months consisted of a single piece of white tough fibrous tissue which proved on microscopy to be dense collagenous tissue indistinguishable from normal tendon without any clear evidence that it derived from muscle (Figs. 2 and 3). The practical significance of this treatment of the biceps muscle is obvious. It provides a useful means of bridging the gap between the detached tendon of pectoralis major and the tuberosity of the radius.

THE OPERATION

Incisions—Two incisions are made (Fig. 4): one extends from the lower end of the delto-pectoral groove down to the junction of the uppermost and middle thirds of the arm; the second incision is L-shaped and situated over the antero-medial aspect of the elbow.

FIG. 3
The biceps converted into tendon: the same case as is illustrated in Figures 2 and 11.

Technique—Through the first incision the insertion of pectoralis major is detached as close to the bone as possible (Fig. 5). The muscle is mobilised from the chest wall by blunt dissection towards the clavicle. The deltoid is then retracted laterally and upwards to allow exposure of the tendon of the long head of biceps running upwards into the shoulder joint. This tendon is severed at the upper end of the bicipital groove and withdrawn into the wound (Fig. 6). The belly of the long head of biceps is freed from the short head by blunt and sharp dissection and all vessels entering the muscle belly are ligated and divided. By retraction it is possible to mobilise the muscle belly to the lowest third of the arm. The remaining neurovascular connections are divided so that the tendon and muscle are completely free down to the tuberosity of the radius. The whole of the long head is then withdrawn through the lower incision (Fig. 7). It will often be found that in long-standing paralysis the muscle belly is adherent to the overlying fascia and sharp dissection is required to free it. Until this has been done it may not be possible to flex the elbow by traction on the proximal tendon of the long head. The long head of biceps is then replaced and its tendon, now visible through the upper incision, is passed through two slits in the tendon of pectoralis major and looped on itself so that the proximal tendon can be brought down again into the distal incision (Fig. 8). The proximal tendon is then buttonholed into the distal tendon with the elbow acutely flexed. Silk stitches are inserted

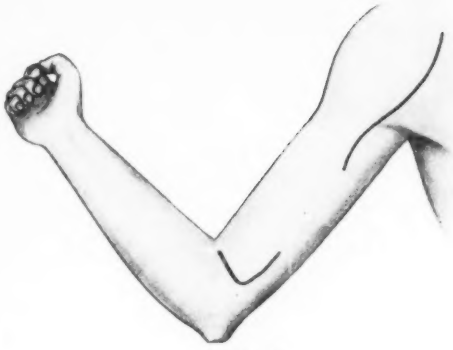

FIG. 4

FIG. 4
The skin incisions.

FIG. 5
Detachment of the insertion of pectoralis major.

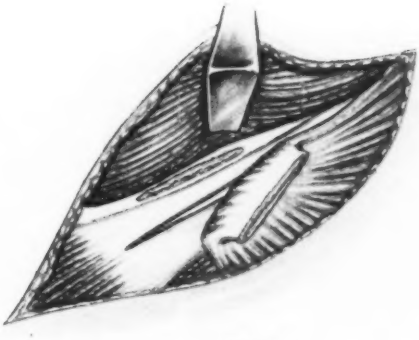

FIG. 5

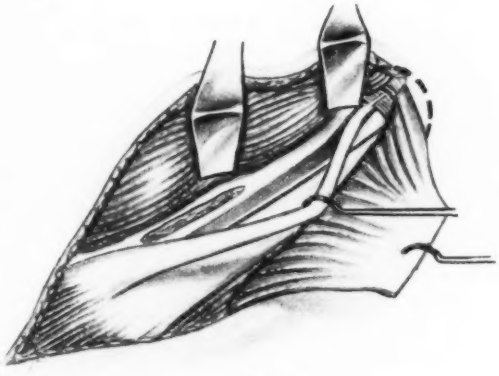

FIG. 6

FIG. 6
Exposure of the long head of biceps which is severed proximally.

at the level of the tendon of pectoralis major and at the distal junction of the tendons. The incisions are then closed.

Post-operative treatment—A plaster back slab is retained for three weeks. At the end of this time re-education is started, but care should be taken to extend the elbow gradually so that active flexion above the right-angle position is maintained. It may be two to three months before full extension of the elbow is possible.

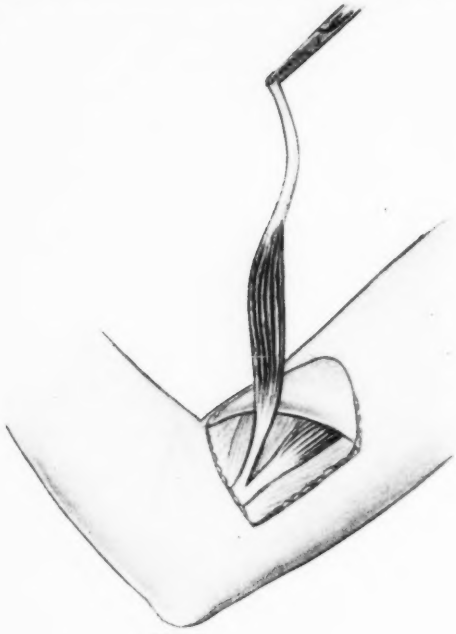

FIG. 7

FIG. 7
Complete mobilisation of the long head of biceps with severance of all vessels entering it above the elbow.

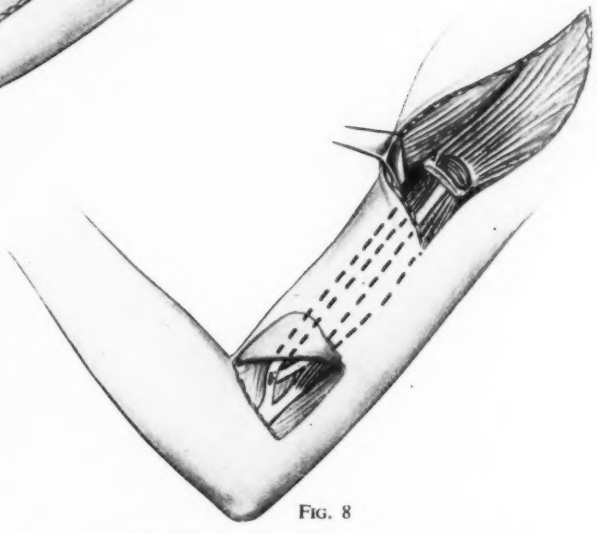

FIG. 8

FIG. 8
The long head of biceps is passed through the severed and mobilised insertion of pectoralis major, then passed distally and sutured to its own tendon of insertion.

RESULTS*

This technique has been employed on eight occasions and in two further cases a slight modification has been used: the tendon of pectoralis major was sutured directly to the long head of biceps after it had been mobilised, the practical difference being that the tension under

* These results differ from those reported by Segal, Seddon and Brooks (1959). Two additional cases are included here, one of arthrogryposis, and the assessment of results was made at a later date. Two of the failures reported by Segal *et al.* were due to simultaneous action of the transplant and the triceps; these were converted into good results (Cases 5 and 9) by transplantation of the triceps into the biceps tendon.

which the transplantation was done was probably less than in the technique described. The results in the ten cases are summarised in Table I. Five patients had suffered a traction lesion of the brachial plexus; there were four cases of poliomyelitis and one of arthrogryposis multiplex. Re-education sometimes included faradic stimulation of the transplant. The

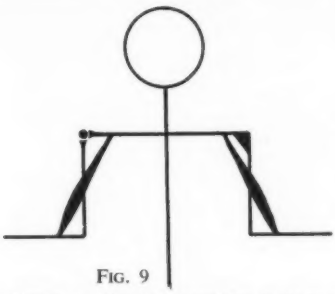

FIG. 9

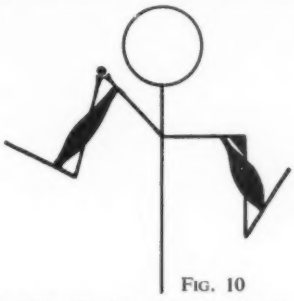

FIG. 10

Figure 9—The left shoulder is flail; the right has been stabilised by an arthrodesis. Figure 10—When the transplant contracts some of its force (*left*) is wasted because of the lack of control of the shoulder. If the shoulder is fixed (*right*) the transplant moves only the elbow.

average duration of post-operative observation was about two and a half years. There have been three excellent results—that is, with active flexion against resistance through a useful range of movement. There were three good and two fair results; in the good and fair results either the range of active flexion did not equal that of passive flexion or the power of flexion was against gravity but not resistance. There were two complete failures, both due to the pectoralis

TABLE I

CLINICAL DETAILS AND RESULTS IN TEN CASES

Case number	Sex	Age (*years*)	Disease	Arthrodesis of shoulder	Duration of paralysis (*years*)	Results				
						Period of post-operative observation (*years*)	Range of flexion		Power of transplant (M.R.C. grading)	Function
							Passive *degrees*	Active *degrees*		
1	F	15	Poliomyelitis	No	7	5	30–full	30–135	4	Excellent
2	F	18	Poliomyelitis	Yes(before)	7	3	20–120	20–100	3	Good
3	M	30	Poliomyelitis	No	1	2	30–140	30–90	2	Failure
4	F	15	Poliomyelitis	Yes (after)	15	1	45–full	45–135	3½	Excellent
5	M	24	Brachial plexus injury	Yes (after)	2	4	20–120	20–90	4	Good* (combined)
6	M	26	Brachial plexus injury	No	2	3	30–130	30–90	3	Fair
7	F	16	Brachial plexus injury	No	1	3	30–full	30–full	4½	Excellent
8	M	21	Brachial plexus injury	No	2	3	30–130	30–90	3	Fair
9	M	22	Brachial plexus injury	Yes (after)	2	1	45–135	45–90	4	Good* (combined)
10	M	9	Arthrogryposis multiplex	No	9	3	35–full	35–60	3	Failure

* Triceps transplantation performed subsequently.

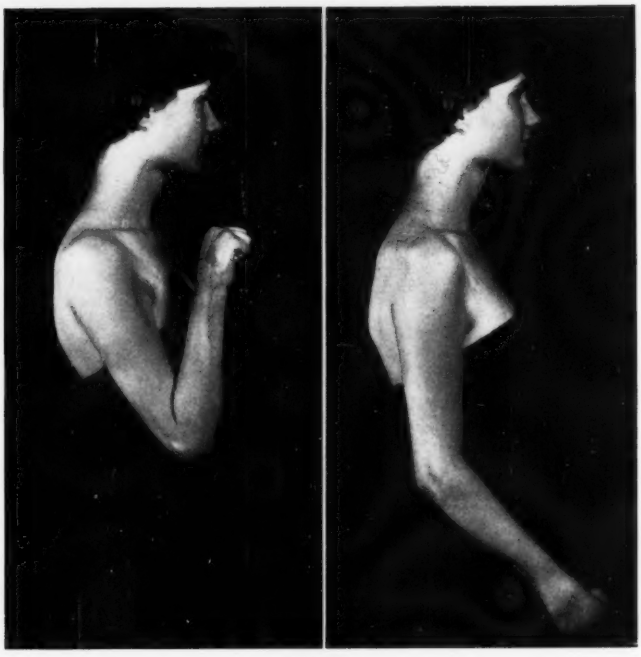

FIG. 11
Result of transplantation of the clavicular portion of pectoralis major by the method described.

FIG. 12
The girl can lift a weight of 4 lb. 11 oz. Control of the shoulder is normal.

major's being too weak. In one, a child with arthrogryposis, the pectoralis muscle was seen to be very flimsy at operation, and in the other, a patient with poliomyelitis, the strength of the muscle was over-estimated.

If the shoulder can be stabilised, either by muscular control or by arthrodesis, the power of a pectoral transplant is greatly enhanced because it acts only on the elbow (Figs. 9 and 10). In the case illustrated in Figures 11 and 12 there was an irreparable lesion of the musculocutaneous nerve and paralysis of the lower part of pectoralis major; all other shoulder muscles were normal and the result of the transplantation was probably the best in the series. In cases 4, 5 and 9 an arthrodesis of the shoulder was subsequently performed with good effect. In Case 1, however, the result was excellent in spite of a flail shoulder. In Cases 5 and 9 a triceps to " biceps " transplantation was subsequently necessary owing to simultaneous action of the pectoralis major and the triceps—a phenomenon frequently encountered in brachial plexus lesions and due to axonal confusion during regeneration.

CONCLUSION

We believe that this technique has several advantages. After poliomyelitis recovery in the clavicular head of pectoralis major may exceed that in the sternal head; there may be considerable but incomplete recovery in both heads and it is then desirable to use all the active muscle available. Girls and women dislike conspicuous scars; the incisions used in this technique are unobtrusive when the arm is by the side.

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TREATMENT OF PARALYSIS OF THE FLEXORS OF THE ELBOW

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This paper presents the results of operations designed to restore active flexion of the elbow. The types of operation considered are: 1) transplantation of pectoralis major into biceps (Clark's (1946) operation and the Brooks-Seddon operation (1959)); 2) transplantation of triceps into biceps; and 3) proximal transplantation of the common flexor and extensor origins—Steindler's operation.

THE CASES

We have studied forty-one patients who had lost active elbow flexion, either from a traction lesion of the brachial plexus or after an attack of poliomyelitis. The average period of post-operative observation was four years and eight months, the shortest period being ten months, the longest eleven years.

METHOD OF ANALYSIS

It proved necessary to assess the subjective as well as the objective results of these operations. It is probably fair to group cases of brachial plexus injury and poliomyelitis together for objective assessment, whereas it can be misleading to do so when gauging subjective results. A slight gain in movement can be most valuable to the patient with poliomyelitis; by contrast the impairment of sensibility which often follows lesions of the brachial plexus may seriously limit the usefulness of the limb despite a significant motor improvement. In every case a full examination of the arm was carried out. Records were made showing the ranges of passive and active movement, the power of individual muscle groups, and simultaneous movements of shoulder, wrist and fingers on flexion of the elbow. In the cases of brachial plexus injury the residual sensory disturbance was noted. The objective results were graded as follows:

Excellent—Powerful contraction throughout the full range of movement.

Good—Contraction adequate to produce at least movement against gravity through a useful range.

Fair—The same power of contraction through a more restricted range.

Failure—Inability to contract against gravity, or ability to produce only a useless range of movement.

Full extension is designated as 0 degrees. A useful range of movement is considered to be an arc of not less than 60 degrees which must include a position of flexion of not less than 120 degrees. A useless range of flexion is of less than 60 degrees from the fully extended position.

Each patient was asked to give his view on the result of the operation. Was it a success? Had it improved the function of the limb as a whole? What work could he do? Had the appearance of the limb improved? The subjective results were graded as follows:

Excellent—" The operation has been a great success."

Good—" It has been successful up to a point."

Poor—" There has been no real change."

Failure—" It has been a disappointment."

RESULTS

The *objective* results are summarised in Table I. On the whole Steindler's transplantation gave the best results, followed closely by Clark's pectoral transplantation, the other two types of transplantation being less satisfactory. However, the results require further analysis because

TABLE I

OBJECTIVE RESULTS

Type of Operation	Excellent			Good			Fair			Failure			Grand totals
	Polio-myelitis	Brachial plexus injury	Total	Polio-myelitis	Brachial plexus injury	Total	Polio-myelitis	Brachial plexus injury	Total	Polio-myelitis	Brachial plexus injury	Total	
Clark's transplantation	3	4	7	1	—	1	—	7	7	1	1	2	17
Brooks-Seddon transplantation	1	1	2	—	—	—	1	2	3	1	2	3	8
Steindler's transplantation	5	2	7	2	—	2	4	—	4	—	—	—	13
Triceps transplantation	—	—	—	1	—	1	1	1	2	—	—	—	3
Total	9	7	**16**	4	—	**4**	6	10	**16**	2	3	**5**	**41**

there are certain advantages and disadvantages peculiar to each method. They are therefore considered under three headings: 1) the effect of operation on the range of passive movement of the elbow; 2) the effect of operation on active and passive supination of the forearm; and 3) associated movements occurring during active flexion.

Passive movement of the elbow (Table II)—Flexion has not been restricted by any operation performed in this series. Limitation of extension, however, has been a frequent sequel. The average limitation was about 30 degrees for all operations. It will be seen from Table II

TABLE II

RANGE OF PASSIVE EXTENSION AFTER OPERATION

Type of operation	Full movement	Restricted movement			Total
		Less than 30 degrees	30–60 degrees	60–90 degrees	
Clark's transplantation . .	11	4	1	1	17
Brooks-Seddon transplantation	—	7	1	—	8
Steindler's transplantation .	—	2	5	6	13
Triceps transplantation . .	—	1	2	—	3

that after Clark's operation eleven out of seventeen patients had full elbow movement; there had been pre-operative limitation of extension in four of the other six. Elbow extension is unlikely to be limited by more than 15 degrees after this operation. The Brooks-Seddon transplantation may restrict extension by about 25 degrees. Transplantation of the triceps may also produce a significant limitation of extension. It is hardly surprising that with the Steindler procedure, and particularly when (as is our practice) both flexor and extensor origins are transplanted, the restriction of extension is considerable. Loss of extension is the price paid for powerful flexion. The average loss of extension after Steindler's operation was 60 degrees. It seems probable that the power of triceps may influence the degree of limitation; in those cases in which triceps was acting at least against gravity the limitation of extension was about 45 degrees, whereas in the nine cases where it was less than the Medical Research Council grading of 3 the average limitation was 65 degrees.

TABLE III

RANGE OF SUPINATION AFTER OPERATION

Type of operation	Range of movement in degrees								Totals
	None		0–45		0–75		Full		
	Passive	Active	Passive	Active	Passive	Active	Passive	Active	
Clark's transplantation . .	—	1	1	4	5	4	4	1	10
Brooks-Seddon transplantation	1	3	3	1	—	—	1	1	5
Steindler's transplantation .	1	2	1	1	2	2	4	3	8
Triceps transplantation . .	1	1	—	—	1	2	1	—	3

Active and passive supination—It is important to know the effect of these operations on the range of active and passive supination of the forearm. It was possible to assess this effect in twenty-six cases in which there was full passive supination before operation (Table III). Clark's operation never restricted passive supination severely, and in all but one case restored a useful range of active supination. After the Brooks-Seddon transplantation passive supination was sometimes restricted; active supination was restored in only two out of five cases. The most significant conclusion to be drawn from this Table is that in our experience Steindler's transplantation has little effect on the range of passive supination.

In only five cases was there active supination through a complete range; once after Clark's operation, once after the Brooks-Seddon transplantation, and three times after Steindler's operation—almost certainly present before operation.

Associated movements (Table IV). *Shoulder*—Undesirable movements of the shoulder during active flexion of the elbow were a common sequel to pectoral transplantation and could seriously impair the result. The movements were shrugging, adduction, and medial rotation of the arm so that the hand hit the chest wall. Unless there was good muscular control of the shoulder and scapula, or unless an arthrodesis had been performed, this complication was frequent. When pectoral transplantation is carried out for lesions of the upper trunk of the brachial plexus, the paralysis is such that no active lateral rotation of the

TABLE IV

ASSOCIATED SHOULDER MOVEMENT AFTER PECTORAL TRANSPLANTATION

Number of cases	Shoulder muscles	Marked medial rotation, adduction, or shrugging of the shoulder on flexion	Results
7	Good control of the shoulder and scapula	None	Excellent 6 Failure 1
11	Variable scapular control; no control of the shoulder	1 None 10 Present	Excellent 2 Fair 6 Failures 3
7	Arthrodesis of the shoulder	None	Excellent 1 Good 2 Fair 4

arm is possible. Furthermore, in cases of poliomyelitis it is rare to find paralysis of the elbow flexors with normal control of the shoulder. In three of the seven cases in which arthrodesis of the shoulder was performed, it was carried out after the pectoral transplantation because

of the undesirable effects just described. In the other four arthrodesis of the shoulder was performed before the transplantation.

Forearm muscles—In all of the thirteen patients on whom a modified Steindler operation had been performed contraction of the forearm muscles caused the hand to go into the clenched fist position during active flexion of the elbow. In only one case, however, was the strength or independence of wrist and finger movements affected, the patient flexing the elbow on attempted extension of the wrist. In no case has arthrodesis of the wrist had to be performed after Steindler's transplantation. One patient whose wrist extensors were weaker than the flexors wears a splint to prevent wrist flexion during active flexion of the elbow.

There is no doubt that after pectoral transplantation active flexion of the elbow is often reinforced by what may be termed " a Steindler effect." It is difficult to assess precisely how much this contributed to the final result. It can be said, however, that of nine patients without useful contributory forearm muscle action, three had excellent results after pectoral transplantation, compared with seven out of thirteen in whom the forearm muscles were strong.

Triceps—In three cases—all of injuries of the brachial plexus—simultaneous contraction of triceps occurred on active flexion of the elbow, thus spoiling the result of the pectoral transplantation. In these three cases the triceps and the flexors of the elbow were paralysed when the patient was first seen. It is impossible to forecast this complication, for in six other cases in which the triceps was paralysed initially and recovered later no simultaneous flexor-extensor action developed. This unhappy complication may be due to cross-regeneration, nerve fibres originally connected with the flexors of the elbow finding their way into distal pathways going to the extensors. In two cases a subsequent transplantation of the triceps into the flexor apparatus was successful.

Comparison of results in patients with poliomyelitis and brachial plexus injuries. *Objective results*—The twenty-one patients with poliomyelitis showed the following results:

9 excellent
4 good } = 62 per cent

6 fair
2 failures } = 58 per cent

The results in the twenty patients with brachial plexus injuries were:

7 excellent = 35 per cent

10 fair
3 failures } = 65 per cent

The factors that might explain the better results in poliomyelitis are: 1) In the poliomyelitis series eleven Steindler transplantations were performed, whereas after brachial plexus injuries there were only two. The results of Steindler's operation are better than those of pectoral transplantation (Table I and Table V). 2) Simultaneous contraction of the antagonist muscle—the triceps—does not occur in poliomyelitis.

TABLE V

COMPARISON OF OBJECTIVE RESULTS OF PECTORAL TRANSPLANTATION AND STEINDLER'S TRANSPLANTATION

Type of operation	Excellent or good	Fair or failure
Clark's transplantation . .	8 (47%)	9 (53%)
Brooks-Seddon transplantation	2 (25%)	6 (75%)
Total	10 (40%)	15 (60%)
Steindler's transplantation .	9 (69%)	4 (31%) *None is a failure*

TABLE VI
SUBJECTIVE RESULTS: THE LIMB AS A WHOLE

Type of Operation	Excellent			Good			Poor			Failure			Grand totals
	Polio-myelitis	Brachial plexus injury	Total	Polio-myelitis	Brachial plexus injury	Total	Polio-myelitis	Brachial plexus injury	Total	Polio-myelitis	Brachial plexus injury	Total	
Clark's transplantation	2	—	2	2	6	8	1	5	6	—	1	1	17
Brooks-Seddon transplantation	—	—	—	3	1	4	—	1	1	—	1	1	6
Steindler's transplantation	3	1	4	6	1	7	2	—	2	—	—	—	13
Triceps transplantation	—	—	—	1	—	1	1	1	2	—	—	—	3
Total	5	1	6	12	8	20	4	7	11	—	2	2	39

Subjective results (Table VI)—It has been impossible for the patients, almost all of whom had undergone other operations on the affected limb, to assess precisely how much benefit they derived from the operation on the elbow. However, they were asked a number of detailed questions about what they could do before and after the operation.

The twenty-one patients with poliomyelitis showed the following results:

5 excellent, 12 good = 81 per cent

4 poor, No failures = 19 per cent

The results in the eighteen* patients with brachial plexus injuries whose functional results could be assessed were:

1 excellent, 8 good = 50 per cent

7 poor, 2 failures = 50 per cent

Although there were fifteen patients who stated that they could use the hand at the level of the face, only nine in fact habitually did so. When patients are accustomed to use the normal

TABLE VII
FUNCTIONAL RESULTS: ELBOW ALONE

Results	Brachial plexus injury	Poliomyelitis	Total
Excellent	12	18	30
Good .	1	1	2
Poor .	5	1	6
Failure .	—	1	1
	18	21	39

limb their only need is to be able to use the affected limb as a help. Consequently, even if they are unable to flex the affected elbow fully function is very good. Twenty patients said that the appearance of the arm had been much improved by the elbow operation, because it

* The other two had amputations through the forearm.

no longer hung limply by the side. No patient complained of the change in appearance due to a 50–90 degrees' flexion deformity of the elbow.

The functional results with reference to the elbow operation alone are summarised in Table VII. It shows clearly how a patient is often better pleased with the operation than is his surgeon. The one failure was after a triceps transplantation when active flexion was not regained and the loss of active extension was regretted.

DISCUSSION

Muscle transplantation is more effective when it is not required to move the elbow through the first 30 or 40 degrees of flexion. The results (assessed objectively) were better when passive extension of the elbow was limited.

In eleven patients with full extension the results were:

4 satisfactory	=	36 per cent
7 inferior results or failures	=	64 per cent

In thirty patients with limited extension the results were:

16 satisfactory	=	53 per cent
14 inferior results or failures	=	47 per cent

When the failures are analysed it becomes apparent that unless a muscle is really strong it is not worth transplanting. For example, in four cases of pectoral transplantation the muscle was weak; it just failed, or was just able to contract against gravity. In two other patients the pre-operative power of the muscle was over-estimated. In a severely paralysed limb it is often tempting to overrate the muscle that is to be transplanted.

COMPARISON OF OPERATIVE TECHNIQUES

Clark's method—This operation rarely limits passive extension of the elbow, which may be a disadvantage. Some active supination is usually restored. It has been impossible to determine whether Clark's transplantation can reinforce a weak biceps, or whether it in fact eliminates such action as is present. It is probable that it does the latter, as can be demonstrated in transplantations carried out elsewhere in the body. If this is so, then transplantation should not be carried out until hope of recovery in the biceps has been abandoned.

Brooks-Seddon method—This technique was devised for those patients in whom either the lower part of pectoralis major was paralysed, the clavicular head being strong, or when the whole muscle was weak. In other words, it was employed for patients who were more severely paralysed than those in whom a Clark transplantation had been carried out.

In both pectoral transplantations there is an indication for arthrodesis of the shoulder in those patients who lack adequate muscular stabilisation of the shoulder. The effectiveness of pectoral transplantation may be enhanced by a " Steindler effect," and when this is so it might well be argued that a proximal transplantation of the flexor and extensor origins would have been preferable. Furthermore, the effectiveness of a Steindler transplant is not so directly concerned with shoulder stability as is the pectoral transplant.

Steindler's method—Transplantation of the flexor and extensor origins can be used to reinforce a weak biceps without either hindering its action or prejudicing further recovery—an important feature in traction lesions of the brachial plexus. Similarly, Steindler's transplant can be used to reinforce a feebly acting pectoral transplant (Le Coeur 1953). The disadvantages of the Steindler transplant are, of course, that any relaxation of the grip allows the elbow to extend. Elbow extension is always limited, the impairment amounting on an average to 60 degrees, though this is often advantageous. Like Carroll and Gartland (1953), and unlike Mayer and Green (1954), we have not aimed at correcting the post-operative contracture. In our experience a pronation deformity is unlikely to result from this operation.

Triceps transplantation—Only one of three operations was a complete success. Loss of active extension is such a disadvantage that it greatly restricts the indications for this operation.

One patient complained bitterly of the fact that she was unable to steady a loaf with her hand while cutting a slice of bread. Its use should be reserved for those cases in which restoration of flexion is imperative, and in which no other transplantation is possible; or in rare instances when simultaneous contraction of triceps interferes with the action of a pectoral transplant or biceps.

Which operation should be done when there are several possibilities? The most important choice lies between pectoral transplantation and Steindler's operation. When there is a free choice the latter is preferable, because pectoral transplantation usually calls for arthrodesis of the shoulder if there is appreciable paralysis of the shoulder muscles; and if there is some action in the biceps it will be reinforced by Steindler's transplantation, whereas it is by no means certain that this is the case with Clark's transplantation. The Brooks-Seddon technique should never be employed unless the biceps is completely and permanently paralysed.

SUMMARY

1. Twenty-one cases of poliomyelitis and twenty cases of brachial plexus injury in which muscle transplantations had been performed to restore elbow flexion have been reviewed. The average follow-up period was four and a half years.

2. The results were graded objectively and subjectively. They were better when passive extension of the elbow was limited; such limitation always occurs after Steindler's operation, but infrequently after pectoral transplantation.

3. The results of pectoral transplantation are good when there is no significant shoulder paralysis; if there is shoulder weakness arthrodesis of the joint may be required to control medial rotation and adduction of the shoulder on flexion of the elbow. In brachial plexus lesions the results of pectoral transplantation may be marred by simultaneous contraction of the triceps. This can be overcome by transplanting triceps into the flexor apparatus. Triceps transplantation is rarely indicated because loss of active extension of the elbow is a grave disability.

4. Subjective results tended to be worse than objective results in brachial plexus lesions because impairment of sensibility in the hand often limited the usefulness of the limb. In striking contrast the subjective results were in general far better than the objective in patients who had had poliomyelitis. In them the smallest gain can be of functional value.

Dr Segal worked in the Insititute of Orthopaedics in 1956 while holding an Anglo-French Exchange Scholarship in Medical Science.

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LATE RESULTS OF REMOVING THE MEDIAL HUMERAL EPICONDYLE FOR TRAUMATIC ULNAR NEURITIS

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In 1950 we reported sixteen operations for the relief of traumatic ulnar neuritis by excision of the medial epicondyle and adjacent supracondylar ridge of the humerus, to which the medial intermuscular septum is attached. This simple operation had provided early results that were gratifying. Pain was cured in all. Sensation and muscle power, although not recovering completely in the short period of observation, showed improvement. Smith-Petersen (1950) stated that he had been using this method independently for ten years and was pleased with the results.

The object of this paper is to report the late results in twenty patients in whom it was possible to follow the progress (Table I).

INDICATIONS FOR OPERATION

1. The epicondyle and adjacent supracondylar ridge were often removed as a preliminary to operations on the elbow such as arthrodesis or arthroplasty in order to mobilise the ulnar nerve, but these cases have not been reported here.

2. When the ulnar nerve has to be sutured a gain in length of up to an inch can be obtained by a preliminary removal of the epicondyle. If some legitimate stretching of the nerve is necessary in order to approximate the ends, as happens when the nerve has been injured near the wrist, the nerve continues to lie in a straight line and is not kinked as it may be when the nerve has been transposed in front of the intact epicondyle. These cases are not included in this paper.

3. There were examples of irritation of the nerve in the groove from such causes as epicondylitis (periosteal new bone), ununited fractures of the medial epicondyle or olecranon, local bursitis and other causes.

4. Cubitus valgus (seven patients) is perhaps the commonest cause of ulnar neuritis by stretching; there was no example of neuritis from cubitus varus.

5. There was no instance of epicondylectomy for recurrent dislocation of the ulnar nerve.

DISADVANTAGES OF TRANSPOSITION OF THE NERVE

Before embarking upon this new procedure it was necessary to consider any disadvantages of the older method of anterior transposition of the ulnar nerve in front of the medial epicondyle, which, on the whole, has given general satisfaction. Although the older operation has been described as an ideal one there appear to be some disadvantages.

1. If the nerve is implanted subcutaneously it is more exposed to injury by contusions and stretching, or it might even be severed in an accident (Murphy 1916). This criticism applies equally after excision of the epicondyle.

2. If the anteriorly transposed nerve is deeply buried in muscle in order to avoid the dangers of a subcutaneous implantation, there sometimes follows a cicatricial contracture with strangulation of the nerve and a corresponding increase of the ulnar neuritis, and a second operation may be necessary to relieve the strangulation (Rand 1944). Cairns (1948), Shaw (1934) and Hoets (1950) quoted six examples of post-operative increase of the ulnar neuritis from pressure when the nerve had been buried in the flexor muscles. If the medial intermuscular septum is not divided when the nerve is brought forward it may be kinked or irritated. Strangulation of the nerve has also been reported at the site of the division of the medial intermuscular septum.

TABLE I

CLINICAL DETAILS IN TWENTY CASES

Case number	Age (*years*)	Cause	Symptoms	Neurological signs	Date of operation	Result		
						Date	Sensory	Motor
1	42	" Car elbow "; traumatic neuritis	Paraesthesia; weakness of hand	Marked paraesthesia	April 1942	May 1957	No pain; paraesthesia persists	Normal
2	45	Cubitus valgus; fracture at 18 months	Pain and weakness of hand	Marked paraesthesia; muscle wasting; complete adductor and interosseous paralysis	September 1945	June 1957	Slight paraesthesia to touch and prick	Normal
3	44	Fracture medial epicondyle 9 years before	" Pins and needles " in ulnar distribution 4 years	All interossei weak; grip weak	February 1946	July 1957	Normal	Normal
4	48	Old humeral fracture; recent blow on elbow	Paraesthesia and weakness	Tenderness behind epicondyle; wasting of ulnar-innervated muscles except F.C.U.	August 1946	June 1957	Normal	Normal
5	45	Fracture medial epicondyle at age 10 (ununited)	Tingling inner side of forearm and little finger	Tenderness behind epicondyle; paraesthesia ring and little fingers	November 1946. Adhesions present	—	Immediate improvement in symptoms. No reply to inquiry	—
6	67	Dislocation elbow at age 16; injury 6 months ago	Three attacks of neuritis; pain and paraesthesia ring and little fingers	Neuroma behind medial epicondyle, which was deformed from old injury	May 1948	June 1957	Normal	Normal
7	29	Cubitus valgus	Numbness of little finger; weakness in hand	Paraesthesia little finger; wasting of interosseous and hypothenar muscles	November 1948	July 1957	Normal	Slight wasting; no weakness
8	10	Cubitus valgus	Ulnar neuritis; pain	None	June 1949	February 1957	Normal	—
9	33	Ununited fracture of olecranon	Pain	None	November 1949	December 1949	No pain	—
10	50	Cubitus valgus since age 3	Pain behind elbow	Wasting in ulnar distribution; paraesthesiae ring and little fingers	February 1950	August 1957	No pain or paraesthesia	Thenar muscles recovered; slight wasting of hypothenar muscles and weakness of interossei

TABLE I—*continued*

TABLE I—*continued*

CLINICAL DETAILS IN TWENTY CASES

Case number	Age (*years*)	Cause	Symptoms	Neurological signs	Date of operation	Result		
						Date	Sensory	Motor
11	40	Cubitus valgus	Pain in forearm; weakness in hand 11 years; contracture of little finger	Tenderness behind epicondyle; clawing of ring and little fingers; fourth dorsal interosseous weak; slight hypothenar wasting	August 1950	November 1951	Normal	Normal
12	47	Ununited fracture of ulna	Numbness and tingling 4 years	Weakness of all intrinsic muscles supplied by ulnar nerve	May 1951	December 1956	Normal	Normal
13	47	Cubitus valgus; fracture at age 7	Sensory symptoms for 4 years	Paraesthesia ring and little fingers. Weakness and wasting of all intrinsic muscles supplied by ulnar nerve	September 1954	September 1956	Temporary relief; recurrence of symptoms	No improvement; arthrodesis of elbow
14	26	Cubitus valgus	Weakness in hand and altered sensation	Paralysis of all intrinsic muscles and of F.C.U. and F.D.P. to ring and little fingers; anaesthesia ring and little fingers	May 1955	? 1957	Symptoms slightly diminished	All muscles recovered except adductor, abductor and three dorsal interossei
15	34	Fracture involving elbow 10 years ago	Pain, paraesthesia and loss of power	Slight wasting of hypothenar eminence	August 1956	June 1957	Normal	Normal
16	54	Friction against enlarged epicondyle	Pain in ring and little fingers; weak grip	Wasting of all ulnar-innervated muscles; neuroma behind epicondyle; paraesthesia in ulnar distribution	September 1956	November 1956	No pain; slight hypo-aesthesia little finger	Muscle bulk nearly normal; slight wasting first dorsal interosseous; grip nearly normal
17	57	Friction neuritis; increased carrying angle; large epicondyle	Pain and numbness in hands for 3 months	Weakness of muscles and paraesthesia in ulnar nerve distribution	January 1957	March 1957	Normal	Nearly normal
18	57	Same as 16	Pain and numbness in hands for 3 months	Weakness of muscles and paraesthesia in ulnar nerve distribution; disc degeneration C.5–6	January 1957	March 1957	Occasional pain and slight sensory loss	Hand slightly weaker than normal
19	34	Traumatic ulnar neuritis; injury 4 years ago; enlargement of medial epicondyle	Paraesthesia; weakness of grip; unable to straighten fingers	Neuroma; clawing of hand; weakness and wasting of interosseous and hypothenar muscles; typical sensory loss	April 1957	June 1957	No pain; minimal sensory changes	Clawing improved; some weakness persists, but improving
20	62	Traumatic neuritis; epicondyle enlarged	Typical paraesthesia, pain and weakness	Neuroma; paraesthesia in fingers, hand and forearm; weakness	May 1957	June 1957	Some numbness in ulnar area of hand	Improvement in power began within few days of operation; now normal function

3. After anterior rerouting, the nerve lies in a sinuous course in front of the epicondyle and it seems more logical and simple to remove the epicondyle so that the nerve can roll forward and remain in a straight line.

4. In order to transplant the nerve in front of the epicondyle about four inches of the nerve has to be mobilised by dislodgement from the groove. The nerve is held in the loop of a tape and retracted forward. The nerve supply to the flexor carpi ulnaris has to be carefully preserved. The superior ulnar collateral artery and other anastomotic vessels are likely to be injured. This handling of the nerve causes increased pain after operation and delay in recovery. If the epicondyle is removed the nerve and sheath roll forward and are not handled at all in many cases. There is less pain after operation and recovery is more rapid (Table I).

TECHNIQUE OF OPERATION

A tourniquet is not essential because bleeding is not severe in the anterior approach. The arm rests on a small table at right angles to the trunk and with the forearm supinated. The medial epicondyle and the supracondylar ridge of the humerus are exposed through a

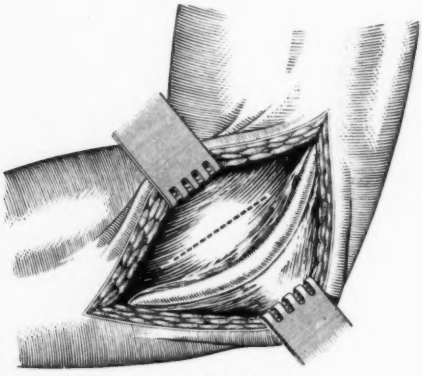

FIG. 1

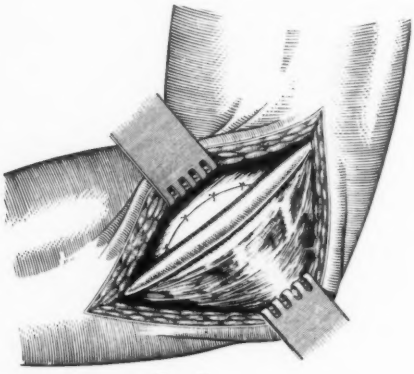

FIG. 2

Figure 1—The medial epicondyle is exposed by an antero-medial incision but the nerve is not dislodged from the groove behind the epicondyle. Figure 2—After the epicondyle and part of the medial supracondylar ridge of the humerus have been removed the nerve rolls forward to the new bed provided by the aponeurosis from the flexor and pronator muscles.

five-inch antero-medial incision (Fig. 1). The aponeurotic origin of pronator teres and the flexor muscles of the forearm is incised over the front of the epicondyle at the base and raised from the front and medial side of the epicondyle with a knife or chisel. This aponeurotic sheet is used later to cover the raw bone that remains after excision of the epicondyle, and thereby reattaches the origin on the muscles to the bone and provides a smooth bed for the nerve (Fig. 2). Up to this point in the operation the ulnar nerve is out of danger because it is lying in the concavity behind the epicondyle and is protected by an anterior band of the ulnar collateral ligament, which passes on to the inner side of the coronoid process. This band must now be peeled from the distal and front part of the epicondyle. With blunt scissors or artery forceps the distal part of the ulnar nerve is exposed just before it passes behind the epicondyle and the proximal part of the nerve is likewise exposed beyond the upper edge of the epicondyle. The nerve and sheath usually need not be further disturbed, but if the nerve and sheath are thickened the sheath should be split after the epicondyle has been excised so that the nerve may be inspected. The epicondyle and one or two inches of the medial supracondylar ridge are removed either by nibbling forceps or by a small chisel. The raw bone surface is smoothed with a Luer forceps. The nerve now rolls forwards and rests in front of

the former site of the epicondyle (Fig. 2). The split aponeurosis is sutured over the raw bone surface to provide a smooth surface for the nerve. The appearance of the elbow before and after operation is illustrated in Figures 3 to 5.

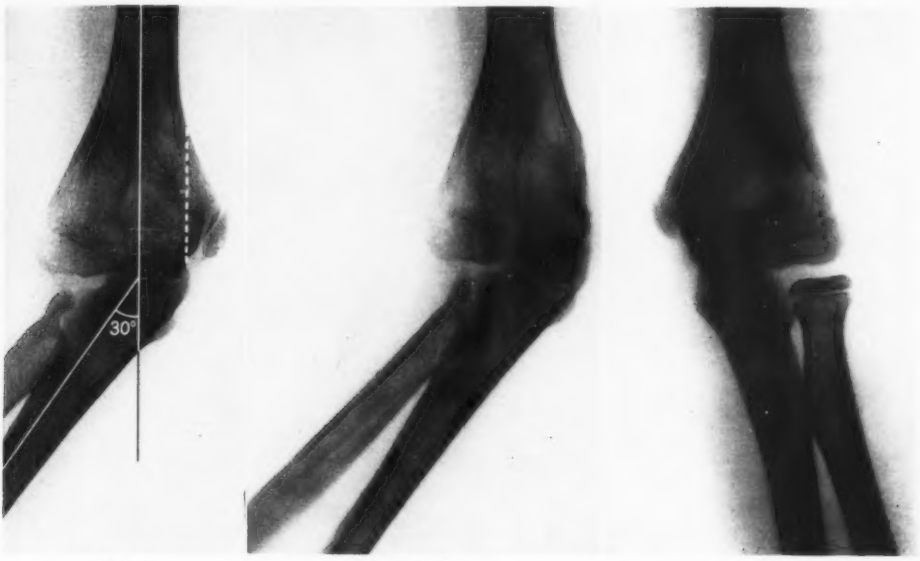

FIG. 3 FIG. 4 FIG. 5

Case 8—Child of ten. Figure 3—Cubitus valgus resulting from removal of head of radius two years before. Figure 4—Appearance after operation. Note the removal of the supracondylar ridge. Figure 5—Opposite elbow for comparison.

RESULTS

Sensory symptoms and signs—Pain disappeared in all except one patient. There was complete recovery of sensibility in eleven patients (55 per cent), incomplete recovery in seven (35 per cent) and no recovery in two (10 per cent).

Motor loss—This was present in all sixteen patients before operation. After operation there was complete recovery in eight (50 per cent), incomplete recovery in seven (44 per cent) and no recovery in one.

CONCLUSIONS

The operation has the advantage of simplicity, and it avoids the slight danger of secondary cicatricial contracture of the nerve when it is transplanted anteriorly and implanted in muscle. There is a slight hazard from external injuries because the nerve is unprotected by the epicondyle.

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THE SHORT LEG IN POLIOMYELITIS

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The purpose of this paper is to discuss the natural history of retarded growth of a leg after paralytic poliomyelitis in childhood.

REVIEW OF THE LITERATURE

In the literature on poliomyelitis references to the occurrence of leg shortening are frequent, particularly in the older text-books on orthopaedic surgery. These references are usually short statements unsupported by clinical details. It is perhaps not surprising that the opinions expressed are conflicting.

I have found five papers in which studies of a series of patients have been made. Barr (1948) observed 371 patients in whom poliomyelitis occurred before the age of sixteen. Green (1952) studied 250 children with paralysis of one leg, presenting the results of this study in summary at the beginning of a paper dealing with the management of leg shortening by epiphysial arrest. Stinchfield, Reidy and Barr (1949) studied 166 adults in whom poliomyelitis had occurred before the age of eleven; of these, the paralysis affected one leg in sixty-four, both legs in 102. Their paper dealt entirely with the relationship of age of onset and severity of paralysis to the degree of shortening. Ring (1957) studied leg shortening in 105 patients, fifty with paralysis of both lower limbs and fifty-five with unilateral lower limb paralysis. Gullickson, Olson and Kottke (1950) investigated eighty-eight patients in whom paralysis of one lower limb had occurred from poliomyelitis three to seven years before, when all the children were under fourteen years of age. The papers of Stinchfield *et al.* (1949), Ring (1957), and Gullickson *et al.* (1950) dealt entirely with the relationship of the degree of paralysis to the shortening.

It is intended in this paper to discuss in addition the incidence and amount of shortening, its distribution, progress and prognosis.

The incidence and degree of shortening—Only Barr's (1948) paper referred to the incidence of leg shortening, which he found in 78 per cent of cases. He considered this figure abnormally high, because it was obtained from " patients with sufficient residual crippling to warrant their seeking medical help." His method of measurement of leg length was not given. In a later article Barr (1949) stated that any child developing poliomyelitis before the age of ten, with considerable difference in paralysis of the legs, was almost certain to develop inequality of leg length. Blount (1956) considered that inequality of leg length " usually " occurs.

The amount of shortening—Tubby and Jones (1903), discussing the relationship of paralysis to shortening, mentioned that " in cases with a very limited palsy you may see as much as five inches of shortening." Bradford and Lovett (1915) stated that " there may be a shortening of one or two inches in the limb of the affected side, or more in exceptional cases." Jones and Lovett (1923) considered that the " amount of leg shortening, except from paralytic dislocation of the hip, is not often great, and an ultimate shortening of more than two inches is unusual." In the first edition (1923) of this text-book is included the comment that " at times it may reach five or six inches." This statement is omitted from the later edition (1929). Whitman (1917) said that the " ultimate shortening varies from one to three inches. In the slighter degrees of paralysis affecting the leg the shortening may be less than one inch, but

when the thigh muscles are paralysed also it may be much more. This inequality is usually noticeable in the feet." Forrester-Brown (1950) noted that " most of the very weak lower limbs do not have one inch of permanent shortening. Severe shortening is more common with tuberculosis than poliomyelitis." Forrester-Brown did, however, mention one patient who developed poliomyelitis at one year of age and in whom no growth in the affected limb occurred after the age of about eight years, the ultimate difference in leg length being nine inches. This is the greatest discrepancy I can find recorded.

Detailed studies indicating the degree of shortening are presented in two papers. Barr (1948) found that 35 per cent of patients developed a discrepancy of one and a half inches or more. Green (1952) noted that 8 per cent developed a shortening greater than two inches.

The effect of age of onset—No clear evidence can be found from the literature of a relationship between the age of onset of poliomyelitis and the degree of shortening. Ring (1957) summarised previous views (Gowers and Taylor 1899, Tubby and Jones 1903, Whitman 1917, and Barr 1948) by saying that " on general principles it seems likely that the factor which retards the growth of the parlysed limb will remain operative throughout the growing period, and that the younger the age of onset the greater will be the shortening." Stinchfield, Reidy and Barr (1949), and Gullickson, Olson and Kottke (1950), however, found no relationship between the age of onset and the shortening. A study of Stinchfield's figures explains the difficulty in resolving this question. In a series of sixty-four patients, each with one paralysed leg, only three had developed poliomyelitis between the ages of six and ten years, and the shortening in these was no less than in twenty-one others whose disease had occurred at an earlier age.

The relationship of shortening to severity of paralysis—There is a considerable debate in the literature about the relationship of the severity of paralysis to the degree of shortening. Jones and Lovett (1929) stated that the " amount of shortening is not necessarily proportionate to the degree of paralysis, slight cases often being accompanied by much shortening and severe cases by moderate shortening." This summarised the opinion of Tubby and Jones (1903), Bradford and Lovett (1915) and Whitman (1917). Forrester-Brown (1950) considered that the occurrence of shortening was " most erratic and bears no direct relationship to the degree of paralysis." Green (1949) found a correlation between the degree of shortening and the amount of paralysis, but emphasised " the great variation."

On the other hand, Gullickson, Olson and Kottke (1950), and Gill and Abbott (1942) found correlation between the severity of paralysis and the extent of shortening. Ring (1957) stated that " limb shortening in poliomyelitis is related directly to the extent of the paralysis." Finally, Stinchfield, Reidy and Barr (1949) and Blount (1956) considered that " shortening may be accurately predicted in the average case by the degree of paralysis present."

CLINICAL MATERIAL

I have studied shortening after poliomyelitis in 225 children in whom paralysis was confined to one leg, thus avoiding the complicating factors which arise if both legs are paralysed. One hundred and thirty-one of these patients were treated at the Princess Margaret Rose Hospital, Edinburgh, and the rest at the Booth Hall Children's Hospital, Manchester, the Biddulph Grange Orthopaedic Hospital, or the Manchester Royal Infirmary. The shortest period of study was five years, and the longest seventeen years. Where limb equalisation procedures had been carried out the period of observation ceased at the time of these operations; also all patients were excluded who had had an osteotomy, a sympathectomy in childhood, or in whom paralytic dislocation of the hip had occurred. With these exceptions, no selection was employed.

Leg length was measured in all cases from the anterior superior spine to the medial malleolus. Shortening had occurred in 219 of the 225 children and it was possible to obtain radiographic records of leg length in 190 patients. (Measurements carried out by this method were accurate to a standard deviation of plus or minus one-sixteenth of an inch.)

The age of onset of poliomyelitis in these patients is shown in Table I, and it will be seen that the greatest incidence was in the first three years of life, and that relatively few children in this series developed the disease at or after the age of eight (Fig. 1).

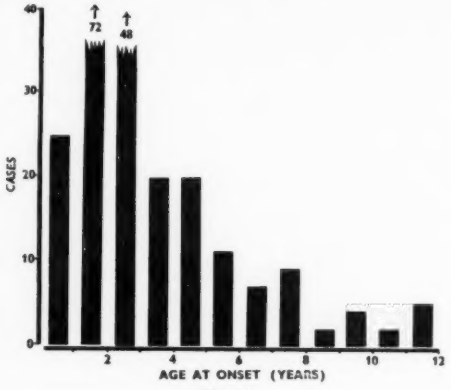

FIG. 1

The age at onset of poliomyelitis in 225 patients studied.

Classification of paralysis—Muscle power in the affected limbs was estimated by the standard method (Medical Research Council 1942) in which individual muscles were awarded points varying from 0 to 5. Seventeen major muscles or muscle-groups were assessed and their

TABLE I

AGE OF ONSET OF POLIOMYELITIS IN 225 PATIENTS WITH PARALYSIS OF ONE LOWER LIMB

Age (*years*)	Number of patients
0–1	25
1–2	72
2–3	48
3–4	20
4–5	20
5–6	11
6–7	7
7–8	9
8–9	2
9–10	4
10–11	2
11–12	5

accumulated points added together. The selection of muscles for grading was the same as that made by Sharrard (1955). If each of the seventeen muscles or muscle-groups was normal (power 5) the total for the limb would be 85. The patients were divided into three groups:

1) mild (85 to 65 points); 2) moderate (64 to 40 points); and 3) severe (39 to 0 points). I appreciate the weakness of this method of classification. It implies that all the seventeen muscles or groups of muscles are equally important, whatever their bulk or their value to the

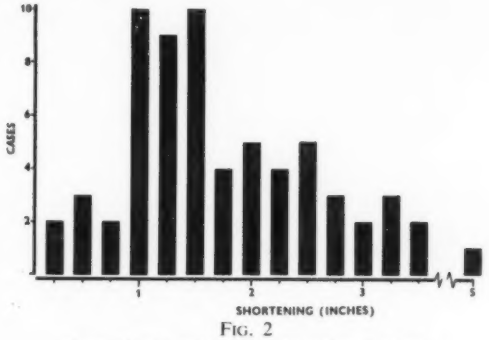

FIG. 2

Shortening at adult life in sixty-five patients.

TABLE II

SHORTENING AT ADULT LIFE IN SIXTY-FIVE PATIENTS WITH PARALYSIS OF ONE LOWER LIMB

Shortening (*inches*)	Number of patients
¼	2
½	3
¾	2
1	10
1¼	9
1½	10
1¾	4
2	5
2¼	4
2½	5
2¾	3
3	2
3¼	3
3½	2
5	1

function of the limb. This method can, therefore, be regarded as only approximate, but at the same time it seems to be the best available.

OBSERVATIONS

Incidence and degree of shortening—In this series of 225 patients there were only six whose legs were of equal length, inequality occurring in 97 per cent.

Sixty-five of the patients, in whom no limb-equalisation operation has been performed, were followed into adult life and the amount of their shortening is shown in Table II and Figure 2, where the discrepancy is seen to vary widely up to three and a half inches but was only once greater than this figure. It may be argued that this series is not unselected and that patients with severe shortening are more likely to have had leg equalisation procedures performed in adolescence, but this criticism is met by considering the state of the sixty-five patients who had never been offered the benefits of leg equalisation. The paralysis of these patients was classified as mild in fifteen, moderate in twenty-three and severe in twenty-seven.

Distribution of shortening—Radiographic records of leg length were studied in 184 patients in whom shortening was present. The distribution of the shortening in these patients is shown in Table III.

TABLE III

THE DISTRIBUTION OF SHORTENING. PARALYSIS ABOVE AND BELOW THE KNEE
(184 patients)

Tibial only	Tibial and Femoral			Femoral only
	T>F	T=F	T<F	
12	94	47	30	1

It will be seen that shortening was present in both tibia and femur in 171 patients or 93 per cent and that the discrepancy was usually greater in the tibia, with only one patient having femoral shortening alone.

It was impossible accurately to predict the distribution of shortening from a study of the distribution of paralysis. For example, a woman had developed a severe paralysis of the right leg when only twelve months old which left her with a flail limb in which all muscles both above and below the knee were paralysed. Although she was unable to stand unsupported without a caliper the total shortening measured radiographically was only one and three-quarter inches. This discrepancy was all tibial.

The distribution of shortening in patients with paralysis confined to muscles below the knee is shown in Table IV.

TABLE IV

THE DISTRIBUTION OF SHORTENING. PARALYSIS BELOW THE KNEE
(Fifty-nine patients)

Tibial only	Tibial and femoral			Femoral only
	T>F	T=F	T<F	
6	30	17	6	Nil

It will be seen that, in fifty-three of these fifty-nine patients, discrepancy occurred in both the femur and the tibia and that shortening was present in the tibia alone in only six.

This is illustrated by a boy who developed poliomyelitis at the age of three, with the paralysis confined to below the knee. The calf muscles, tibialis anterior and tibialis posterior of one leg only were affected, but nine years later the shortening measured radiographically was one inch, which was equally distributed between tibia and femur.

Progress of shortening—Records of leg length were available three years after the onset of the disease in fifty-six patients. Shortening was present at that time in fifty-two.

To study the progress of shortening, only those patients were considered in whom radiographic records of leg lengths were available, and in whom the period of observation was at least nine years; 130 patients satisfied these criteria.

Three patterns of progress of shortening were revealed by this study (Fig. 3): 1) Rapidly progressive, in which two and a half inches or more of discrepancy occurred within nine years or less of the onset of the disease; 2) slowly progressive, in which discrepancy increased slowly year by year and amounted to two to three inches by adult life; and 3) non-progressive, in which a discrepancy of up to one and a half inches was present five years after the onset of the disease, then remaining constant until growth ceased.

There was no evidence from this study that reduction of shortening ever occurs.

A boy who developed a severe paralysis of the left leg at the age of twelve months exemplifies the rapidly progressive growth pattern. He had a leg completely paralysed except for the hip flexors (power 4) and he could not stand without a caliper. Nine years after the onset of paralysis his left leg was three and a quarter inches short.

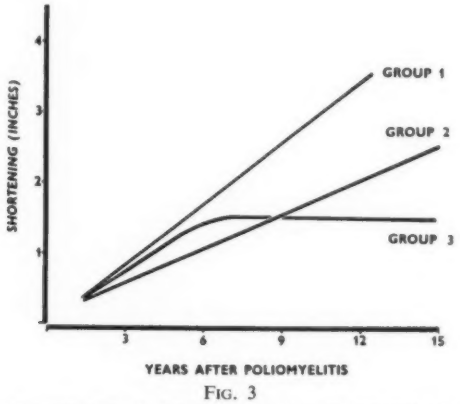

FIG. 3

The progress of shortening in 130 patients studied.

The incidence of these three types of growth disturbance was: rapidly progressive 12 per cent; slowly progressive 26 per cent; and non-progressive 62 per cent. The relation of these three types of growth disturbance to the severity of paralysis is shown in Table V.

TABLE V

RELATIONSHIP OF PROGRESS OF SHORTENING TO SEVERITY OF PARALYSIS IN 130 PATIENTS

Progress of shortening	Classification of paralysis			Total
	Mild (85–65 points)	Moderate (64–40 points)	Severe (39–0 points)	
Rapidly progressive	—	2	14	16
Slowly progressive	—	12	22	34
Non-progressive	38	32	10	80

It will be seen that all the patients in whom the paralysis was mild developed non-progressive shortening. When the paralysis was severe the shortening which developed could

follow any of the three patterns. Clinical examination and study of the blood supply (see later), and of the distribution of the paralysis, failed to explain the wide disparity in progress of shortening which may develop in these patients with a severe paralysis.

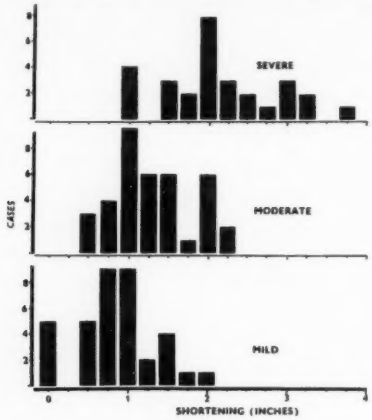

FIG. 4

Relation of severity of paralysis to shortening measured radiologically in 102 patients.

TABLE VI

SHORTENING NINE YEARS AFTER POLIOMYELITIS IN 102 PATIENTS WITH UNILATERAL LOWER LIMB PARALYSIS

Shortening (*inches*)	Severity of paralysis		
	Mild	Moderate	Severe
0	5	—	—
¼	—	—	—
½	5	3	—
¾	9	4	—
1	9	9	4
1¼	2	6	—
1½	4	6	3
1¾	1	1	2
2	1	6	8
2¼	—	2	3
2½	—	—	2
2¾	—	—	1
3	—	—	3
3¼	—	—	2
3½	—	—	1

Relationship of severity of paralysis to shortening—Radiological measurements of leg length were available in 102 patients nine years after the onset of the disease (Fig. 4, Table VI).

The paralysis in these patients was classified as mild in thirty-six, moderate in thirty-seven and severe in twenty-nine.

When the paralysis was classified as mild the shortening ranged from nothing to two inches; when moderate the shortening ranged from one-half to two and a quarter inches, and when severe from one to three and a half inches.

It may be concluded that, though in general the more severe the paralysis the greater the shortening, this does not always follow. A mild paralysis is always associated with a mild shortening, but severe paralysis may be associated with either mild or severe shortening.

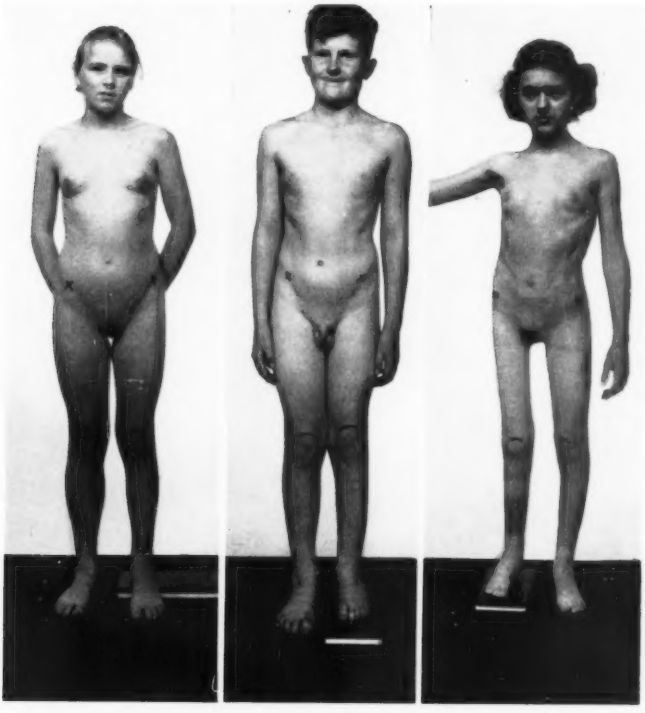

FIG. 5

Three children with one inch of shortening nine years after poliomyelitis at the age of two. The degree of paralysis was: the girl on the left, mild; the boy, moderate; the girl on the right, severe.

There is no constant association between the severity of muscle paralysis and the discrepancy in leg length and it is impossible accurately to predict shortening. Figure 5 illustrates three children who all developed poliomyelitis when two years old, and were observed for the same period of nine years. The shortening measured radiographically was one inch in all three patients. The girl on the left had a mild paralysis, the boy in the centre a moderate, and the girl on the right a severe paralysis.

No relationship could be found in this study between the amount of shortening and the incidence of paralysis of any individual muscle-group.

Effect of age at onset—Complete study of the effect of the age at which poliomyelitis occurred was not possible in this series, for relatively few children developed the disease at eight years of age or older (Fig. 1).

In Table VII and Figure 6 the shortening at adult life is shown in those developing the disease in the first two years of life, and those developing it later.

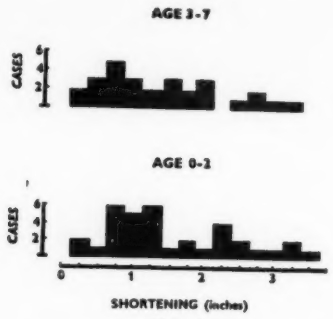

FIG. 6

The effect of age of onset of poliomyelitis on the degree of shortening in sixty-four patients studied.

TABLE VII

RELATIONSHIP BETWEEN THE AGE OF ONSET OF POLIOMYELITIS AND THE DEGREE OF SHORTENING IN SIXTY-FOUR PATIENTS

Shortening (*inches*)	Age (*years*)	
	0–2	3–7
¼	2	2
½	1	3
¾	6	5
1	5	3
1¼	6	2
1½	1	3
1¾	2	2
2	1	3
2¼	4	—
2½	2	1
2¾	1	2
3	1	1
3¼	2	1
3½	1	1

It will be seen that there is no significant difference in the range of shortening which may occur in the two groups. A child who is aged seven at the onset of poliomyelitis may still develop severe discrepancy.

Influence of vascularity—Study of the effects of poliomyelitis on the blood supply of the limb is difficult, for as far as I am aware no simple and yet accurate method is known for the estimation of the blood supply of a leg. An investigation was carried out to determine whether

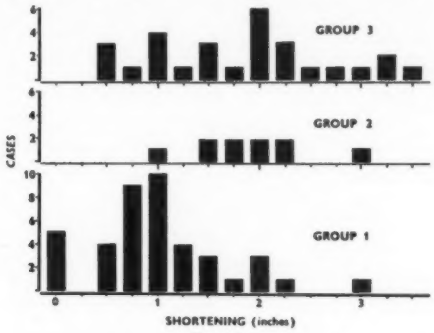

FIG. 7

The relation of vascularity to degree of shortening in seventy-nine patients studied. Group 1—No vascular changes. Group 2—Some coldness of the leg, but no symptoms. Group 3—A very cold leg, often with chilblains and cyanosis.

TABLE VIII

RELATIONSHIP OF VASCULARITY TO SHORTENING (SEVENTY-NINE PATIENTS) PERIOD OF OBSERVATION—NINE YEARS

Shortening (*inches*)	Vascularity		
	Group I	Group II	Group III
0	5	—	—
¼	—	—	—
½	4	—	3
¾	9	—	1
1	10	1	4
1¼	4	—	1
1½	3	2	3
1¾	1	2	1
2	3	2	6
2¼	1	2	3
2½	—	—	1
2¾	—	—	1
3	1	1	1
3¼	—	—	2
3½	—	—	1

a cold blue limb was more likely than a warm pink one to develop severe shortening. Patients were divided into three groups: Group I, no vascular changes; Group II, some coldness of the leg, but no other symptoms; Group III, a very cold leg, often with chilblains and cyanosis.

The results of this study are shown in Table VIII and in Figure 7.

It will be seen that patients with severe vascular changes in the leg (Group III) may show as little shortening as half an inch or as much as three and a half inches. A cold blue limb was not more likely to develop severe shortening.

Prognosis of leg shortening—One of the difficulties of this study was the large number of variable factors. The prognosis should be analysed for children developing poliomyelitis at each year of life, and observed to full growth. When arranged in this way the figures in this series were not large enough to be of statistical significance, particularly as there were few children developing poliomyelitis in the older age groups.

The prognosis has been studied in one group of children only, namely, those who developed poliomyelitis in the first three years of life, and who were observed for nine years. The results are shown in Table IX.

TABLE IX

THE PROGNOSIS OF LEG SHORTENING

Onset of poliomyelitis, 0–3 years Children observed for nine years PARALYSIS BELOW THE KNEE ONLY		
Paralysis	Number of cases	Shortening range (*inches*)
Calf only	5	½–1¾
Tibialis anterior only	8	0–1¼
Other muscle-groups	20	¼–1½

Two conclusions are apparent from this Table. First, whether the paralysis involved only one muscle or all the muscles below the knee the range of shortening was similar. Second, no child with a paralysis only below the knee showed a discrepancy greater than one and three-quarter inches.

In Table X the prognosis of leg shortening for children with paralysis above and below the knee has been outlined.

TABLE X

THE PROGNOSIS OF LEG SHORTENING

Onset of poliomyelitis, 0-3 years Children observed for nine years PARALYSIS ABOVE AND BELOW THE KNEE		
Paralysis	Number of cases	Shortening range (*inches*)
Mild	6	½–1½
Moderate	22	½–2¼
Severe	23	1–3½

Increased limb growth in poliomyelitis—Few references can be found of the occurrence of increased growth in a leg paralysed by poliomyelitis. It was first mentioned by Seeligmüller (1879), who noted lengthening of the paralysed leg in two of seventy-five children with poliomyelitis. In one, a child two years old, the totally paralysed leg was the longer by

two and a half centimetres one year after the disease; in the other, a child of three and three-quarter years old, the paralysed leg was one and a half centimetres longer than the other two years after the acute phase. Kalischer (1899) described a child who developed poliomyelitis when one and a half years old and in whom three months later the affected leg was two centimetres longer than its fellow. He noted that three years later the leg had become one centimetre shorter than the normal limb. Tubby and Jones (1903) described two cases seen in June 1900. In one, the paralysed leg was three-quarters of an inch longer than the other after fourteen years; in the other, with a bilateral paralysis, the more severely paralysed leg was one inch longer. No further details were given. Vulpius (1912) stated, "I myself have frequently seen cases of elongation of the leg. But it was only an apparent lengthening, due either to contracture of the abductors and tilting of the pelvis, or to paralytic forward dislocation of the hip joint. In two patients the discrepancy appeared to amount to one and a half to two centimetres." None of these records of leg length could have been radiographic. More recently Green (1952) noted lengthening of a paralysed limb during the first year of the paralysis, but this always proved temporary. James (1958) has seen one case of a totally paralysed leg one inch longer than its fellow.

FIG. 8

Radiograph showing fusion starting in the lower femoral and upper tibial epiphysial plates of the right knee (shown on the left of this Figure).

In this study seven patients with true lengthening were encountered. Four were found during clinical examination within one and a half years of the onset of the disease, and the measurements were confirmed by radiographic records of leg length. A systematic study of leg length was therefore carried out on ten children who developed poliomyelitis involving one leg only in the summer of 1954, and who were observed for the same period of two years. Three showed lengthening of the paralysed leg. The discrepancy in all seven cases was mild, being a quarter to half an inch. Six of these seven patients had suffered a severe paralysis. Valgus deformity of the femoral neck sometimes occurs after poliomyelitis, and it was at first assumed that this might explain the increased length. Four of these patients, however, had femoral necks with only a mild degree of valgus deformity, and in only one could the lengthening be completely explained in this way. It is curious that the four patients in whom the leg lengthening was detected during routine clinical examination had been treated on hip abduction splints. The significance of this observation, like the etiology of the lengthening itself, is obscure. These four patients have now been observed for five or more years, and they all have developed shortening in the paralysed leg.

No patient was found in this series with lengthening of the paralysed leg five years or more after the onset of the paralysis.

It may be concluded that lengthening of a paralysed leg can occur during the first two years after the onset of the paralysis, but is always a temporary phase. It is possible that this lengthening is more common than is generally realised.

The etiology of leg shortening—The cause of leg shortening is unknown. However, one observation is worthy of mention.

Premature epiphysial fusion was noted in only two patients out of 184 who had a discrepancy in leg length shown radiographically. In one, fusion occurred in the lower femoral epiphysial plate a few months after supracondylar osteotomy for knock-knee. The fusion was perhaps as much due to the osteotomy as to the poliomyelitis. This patient then rapidly developed a further three and a half inches of shortening in the same number of years. At the time of a leg-lengthening operation when he was fifteen years old the total discrepancy was four and a half inches. This patient has not been previously mentioned in this paper because those children on whom an osteotomy had been performed were excluded from the study of the natural history of leg shortening. The other patient with premature epiphysial fusion, a girl, developed a complete paralysis of all the muscles of the right leg when twelve months old in 1932. Radiographs in June 1935 showed fusion starting in the lower femoral and upper tibial epiphysial plates (Fig. 8). The patient was not seen again until adult life, when shortening measured radiographically amounted to five inches (Fig. 9). This was the most severe discrepancy seen in this series, and this patient was the only one to reach adult life with a shortening of greater than three and a half inches.

FIG. 9

A woman who had had poliomyelitis when twelve months old showed five inches of shortening in a flail leg. This was the greatest in the series.

CONCLUSIONS

A study of limb shortening after poliomyelitis in 225 children in whom paralysis was confined to one leg shows:

1. The paralysed leg became shorter than its fellow in 219 patients (97 per cent).
2. The discrepancy in leg length only once exceeded three and a half inches.
3. Both the tibia and the femur were shorter than their fellows in 171 out of 184 studied (93 per cent). In only one patient was the femur alone shortened.
4. Three patterns of progress of shortening are described. No evidence was found that reduction of shortening ever occurs.
5. It is impossible accurately to predict shortening. In general, the more severe the paralysis the greater the shortening, but there are notable exceptions.
6. No relationship could be found between the amount of shortening and the incidence of paralysis of any individual muscle-group.
7. There was no significant difference in leg shortening in adult life between those who had developed the disease in the first two years of life and those who had developed it later.
8. A cold blue limb is not more likely to undergo severe shortening.
9. When the paralysis was confined below the knee the greatest shortening seen was one and three-quarter inches. When muscles both above and below the knee were involved severe paralysis may produce shortening up to three and a half inches.
10. Lengthening of a paralysed leg can occur during the first two years after the onset of the disease, but this is always a temporary phase.
11. The cause of leg shortening is unknown. In only two patients in this series was there evidence of premature epiphysial fusion.

My thanks are due to the members of the Consultant Staff of the hospitals in which the patients were treated for permission to study their cases and their records.

I am most grateful to Mr D. L. Savill and to Mr G. P. Mitchell for their help and criticism in the earlier part of this work, and to Mr D. Ll. Griffiths for reading and criticising the manuscript.

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CORRECTION OF THE OUTWARDLY ROTATED LEG FROM POLIOMYELITIS

Preliminary Communication

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The outwardly rotated leg as an after-effect of paralysis of the gluteus medius and minimus muscles is one of the common complications of poliomyelitis. In consequence the patient drags his stricken leg awkwardly forward, and the femoral head in its unphysiological position further aggravates a statically troubled gait in a progressive fashion.

Dissatisfied with the methods of treatment used hitherto I have attempted to develop a simple and effective method of correction.

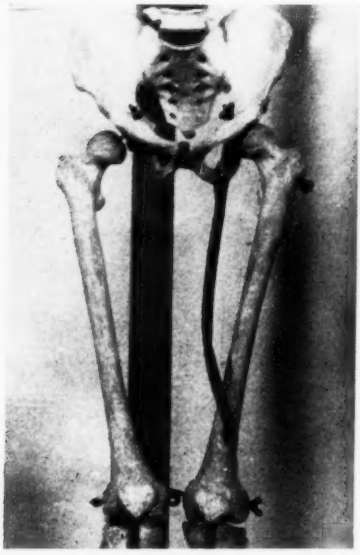

FIG. 1

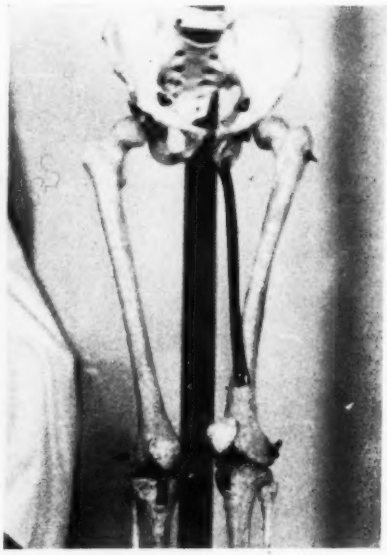

FIG. 2

Model to show the mechanism of the transplant. Figure 1—Position of limb at rest. Figure 2—Forward movement of limb. The graft under tension pulls the femur into medial rotation.

Rotation osteotomy of the femur fails to align physiologically the whole of the leg, and arthrodesis of the hip, although useful in some respects, is a rather crippling operation. Transplantation of the iliopsoas muscle from its insertion at the lesser trochanter to the lateral part of the greater trochanter (Mustard 1952), may provide a solution in a number of cases, but this too is a rather formidable operation, and in addition it severely impairs the original function of the transplanted muscle.

Years ago I tried to dissect a strip of the iliotibial tract and to sling it forward from behind under the attachment of the vastus lateralis, in order to rotate the femur forward by

action of the tensor fasciae latae. This method failed, the short lever apparently being too weak to move the whole leg. The answer was therefore sought in a transplant providing longer leverage with the possible avoidance of action against gravity. The hamstrings seemed capable of providing such action.

THE OPERATION

A medial longitudinal incision is made over the lower third of the femur. The hamstrings are identified. The semitendinosus muscle, if available, is considered most suitable for transplant because of its long tendon. It is dissected up to the lower medial third of the femur, and the tendon is brought under the quadriceps (vastus and rectus) to the antero-lateral part of the femur about a small hand's width above the knee joint and threaded through a horizontal tunnel drilled from the lateral to the medial aspect of the bone, where its end is fixed to the bone, or to the tendon itself at the point of entrance into the drill hole. The semimembranosus muscle, or a combination of more than one muscle from the medial hamstring group, is equally suitable.

When no medial hamstring is available the biceps may be used, its tendon being passed behind the femur and fixed to the medial surface of the bone at the same level. If only one

FIG. 3

FIG. 4

Case 4. Figure 3—Before operation: lateral rotation deformity. Figure 4—Range of active medial rotation after operation.

medial hamstring is available but the biceps is powerful I prefer to use the biceps. In one patient in whom the semimembranosus—the only acting medial hamstring—was used for transplantation the remaining strong biceps was thought to be responsible for the development of knock-knee.

Figures 1 and 2 show the mechanism of the transplant, and indicate how little power is needed for medial rotation. The femur, moved forward by active muscle power or simply by a swinging movement, automatically rotates medially by application of the one-sided " brake." Every bit of active muscle power improves and reinforces this movement. I have transplanted muscles with a grading of 3 with good results.

RESULTS

The results in seven cases are shown in Table I, and illustrative photographs are reproduced in Figures 3 and 4. In assessing the results the term " excellent " was used for a gait without sway from the hip and with medial rotation of the leg possible with the heel off the ground. " Good " meant a swayless or nearly swayless gait, the foot coming down in good position while walking and medial rotation possible with the heel on the ground. " Fair " gave allowance for some sway from the hip, but less than before operation, the foot coming down

with little or no lateral rotation, but with no active medial rotation. Lack of appreciable change from the condition before operation would have been called a poor result. Six of the seven patients subjected to this type of transplant ranged from four to seven years of age;

TABLE I

CLINICAL DETAILS AND RESULTS (SEVEN CASES)

Case number	Age (*years*)	Length of follow-up	Transplant used	Result	Complications
1	5	15 months	Semitendinosus	Good	—
2	7	14 months	Biceps	Fair	—
3	7	21 months	Semitendinosus	Good	Moderate knock knee
4	4	7 months	Biceps	Excellent	—
5	5	14 months	Semitendinosus	Excellent	—
6	47	36 months	Semitendinosus. Semimembranosus	Good	—
7	6	9 months	Semimembranosus	Good	—

the seventh was a woman of forty-seven who was operated upon with good result after an arthrodesis of the knee for the same condition. It was remarkable that all the patients needed very little re-education in the use of the transplanted muscle.

SUMMARY

1. A method of correcting poliomyelitic lateral rotation deformity of the thigh by transplant of one or more of the hamstring muscles to the femur is described.
2. The results in seven cases are recorded.
3. Though it is emphasised that this is no more than a preliminary communication and the number of patients so treated is small, the satisfactory results suggest that the procedure is mechanically and physiologically sound.

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CONGENITAL SHORT FEMUR

Simple Femoral Hypoplasia

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Defects of femoral development may take the form of complete or partial absence of the bone or a failure of growth without obvious loss of bony structure. Mouchet and Ibos (1928) and Nilsonne (1928) presented classifications of femoral defects; their observations were based primarily upon the study of radiographs and their classifications failed to emphasise how gentle may be the gradation from simple hypoplasia to complete absence of the femur. In separating patients with simple hypoplasia from other types of congenital femoral shortening it is accepted that the deformities probably differ in degree only, but as the physical and radiological features are so well marked it seems reasonable to regard simple femoral hypoplasia as a distinct clinical entity.

Patients with congenital shortening of the femur without gross radiological defects usually retain a normal femur throughout childhood, although a small proportion may develop a coxa vara deformity. Changes in the femoral neck can usually be predicted from the early radiographs, and these patients, who often develop considerable shortening and deformity, are not included in this study. The major group, simple femoral hypoplasia without coxa vara, present primarily as problems of limb equalisation. With an increasing interest in the control of growth by epiphysial stapling during childhood it has become important to determine the natural history of this condition, and to indicate the prognosis of the inequality, and with this in view the present investigation has been undertaken.

CLINICAL MATERIAL

From an examination of the records of the Royal National Orthopaedic Hospital and from subsequent examination of those patients in whom congenital shortening of the femur had been diagnosed, eight examples of femoral shortening without coxa vara are available for discussion. A similar review of the patients at the Hospital for Sick Children has yielded eleven further cases (Table I). For most of the patients serial radiographs and scanographs covering a period of many years are available, and most were either adult or approaching maturity.

CLINICAL FEATURES

With severe shortening of the femur the diagnosis is seldom in question and is made at birth, for the baby has a minute femur, often with a bulky but otherwise normal thigh. Defects of this severity are sometimes associated with other limb deformities, of which the commonest is a partial or complete absence of the fibula.

When the disturbance of growth is less marked shortening may not be noticed until the child begins to walk. At this stage the gait is characteristic, with the child walking on the toes of the short leg, which is held in lateral rotation (Fig. 1), in sharp contrast to the child with a short leg from congenital dislocation of the hip. The thigh appears bulky and is often bowed laterally and the patella is high and small (Fig. 2). There is usually a unilateral genu valgum. Clinical examination confirms that the shortening is confined almost completely to the thigh; movements of the hip are very occasionally limited, and two of the patients in this series showed limitation of abduction, one of them also having a fixed flexion deformity. One constant feature is the gross increase in lateral rotation of the hip, which is usually 90 degrees

or more, whereas medial rotation is absent or limited to a few degrees. Although the foot is held in equinus there is no contracture of the tendo calcaneus unless uncorrected shortening has remained for many years.

The clinical diagnosis of the congenital short femur thus rests on the combination of a short thigh, often bowed laterally, an apparent increase in muscle bulk, and an increase in the lateral rotation of the hip. The distinction from congenital dislocation of the hip and

TABLE I

SIMPLE FEMORAL HYPOPLASIA

Case number	Sex	Age	Shortening in *inches*	Treatment	Associated condition	Radiograph
1	M	14	2½ at 11 years	Stapled at 11 years	—	Cortical sclerosis
2	F	32	2½ „ 30 „	Femoral shortening	—	Normal
3	F	16	5¼ „ 8 „	Amputation through knee	Congenital absence of fibula	Normal
4	M	15	2½ „ 10 „	None	—	Cortical sclerosis
5	F	15	2 „ 11 „	Stapled at 11 years	—	Cortical sclerosis
6	F	10	2 „ 10 „	None	Congenital amputation right foot	Normal
7	M	15	3 „ 14 „	Epiphysiodesis at 14 years, also supracondylar osteotomy	—	Cortical sclerosis
8	M	53	2½ „ 53 „	None	—	Cortical sclerosis
9	M	3	1½ „ 3 „	None	—	Normal
10	M	13	1½ „ 13 „	None	Fractured short femur aged 9 years	Cortical sclerosis
11	F	3	½ „ 3 „	None	Fixed deformity of hip treated by plasters	Cortical sclerosis
12	F	3	½ „ 3 „	None	—	Cortical sclerosis
13	F	16	2 „ 9 „	Stapled at 9 years	—	Cortical sclerosis
14	F	13	1½ „ 11 „	Stapled at 11 years	—	Normal
15	M	1½	1 „ 1½ „	None	—	Normal
16	F	3	1½ „ 3 „	None	—	Delayed head ossification
17	M	9	2 „ 9 „	None	—	Bowing and cortical sclerosis
18	M	6	2 „ 6 „	None	—	Cortical sclerosis
19	M	5	1½ „ 5 „	None	—	Cortical sclerosis

infantile coxa vara is not difficult, except in the occasional child who presents with limitation of hip abduction.

The earliest radiographs show shortening but nothing else except perhaps delay in ossification of the head of the femur (Fig. 3); in many patients the shaft of the femur is bowed laterally (Fig. 4) and there may be an area of sclerosis on the outer femoral cortex (Fig. 5). In the infant the difference in femoral lengths may be apparent upon the ordinary radiographs, or may require scanographs for its detection. In older patients the

difference in length is more marked, and the upper epiphysial cartilage may be broader than normal. A radiograph of a femur, identical with its fellow, apart from the shortening, is not, however, uncommon (Fig. 6). When the femur is grossly bowed, the shortening is sometimes attributed to an intra-uterine fracture, but the associated retardation of epiphysial development in femoral hypoplasia usually makes the diagnosis clear. In view of the progressive shortening which develops in this condition, its distinction from a malunited fracture is of some importance. Simple hypoplasia of the femur, which has a relatively good prognosis, must be distinguished from congenital shortening of the femur with coxa vara, in which the shortening of the limb

FIG. 1

FIG. 2

Figure 1—Congenital shortening of the right femur, showing the characteristic position of the leg held in lateral rotation with an equinus position of the foot.
Figure 2—Congenital shortening of the right femur, showing the high patella and bulky thigh.

may be much more severe. Radiographs, even during the first year, will usually indicate changes in the femoral neck in the latter group. These changes are elevation of the greater trochanter and broadening of the upper metaphysis of the femur, and they are followed later by an increasing varus deformity of the femoral neck (Figs. 7 and 8).

ETIOLOGY

There have been no studies of the primary nature of this dysplasia of the femur, and observations must therefore be limited to deductions from clinical observations and from radiographs. There is no evidence of a familial defect apart from its occurrence in this series in one pair of twins. In these children the presence of a short femur in one led to the examination of the other and its detection. It has been suggested that congenital coxa vara and the congenital short femur are variations of the same congenital anomaly (Golding 1938 and 1948). It is undoubtedly true that the more severe type of femoral shortening with gross defects in ossification in the upper end of the bone have a strong resemblance to the coxa vara which may develop in the short femur. Simple hypoplasia of the femur without coxa vara sometimes

FIG. 3

FIG. 4

Figure 3—A short femur with delayed ossification of the secondary centre for the head on the left and apparent widening of the upper epiphysial plate. Figure 4—The left femur shows marked bowing in the mid-shaft and the apparent varus deformity is due to angulation at this point rather than in the neck. (Radiographs later in childhood confirmed the absence of coxa vara.) Compare Figures 7 and 8.

FIG. 5

FIG. 6

Figure 5—Congenital shortening of the left femur with genu valgum and a characteristic area of cortical thickening on the outer side of the shaft. Figure 6—Congenital shortening of the right femur without any characteristic radiological stigmata.

FIG. 7

Congenital shortening of the left femur with cortical sclerosis and a broad upper metaphysis. This type of deformity must be distinguished from simple hypoplasia because it proceeds to coxa vara, as shown in Figure 8.

FIG. 8

The same patient as in Figure 7, showing the development of coxa vara.

shows broadening of the upper epiphysial cartilage of the femur and an area of cortical sclerosis and bowing, suggesting that these two defects may again be closely related. The disturbance of growth in these patients, with or without coxa vara, must be primarily a defect of endochondral ossification. The cortical sclerosis probably indicates excessive new bone formation by the periosteum in the early stages of femoral development, and growth in breadth of the femur is not disturbed. Broadening of the upper epiphysial plate seems to indicate a failure of the metaphysis to replace cartilage by bone, and this hypothesis is confirmed by the delay in appearance of the bony nucleus for the head of the femur. It is probable that a primary defect of cartilage is responsible both for the delay in ossification, and for the bowing of the bone.

PROGNOSIS

There is a progressive disturbance of femoral growth, and despite a seemingly normal radiological appearance, the difference between the limbs increases during the period of growth. Such evidence as there is suggests that the time of epiphysial fusion is unaffected. A review of the annual scanographs which are available for most of these patients indicates that the disturbance of growth, year by year, remains relatively constant. A general guide to the prognosis can thus be given when the first measurements are made. If the length of the shorter femur is expressed as a proportion of the normal one at any period during childhood it will be found that the two bones at maturity bear a similar relationship in length. Thus a child with a femur four-fifths the length of its fellow in infancy will show a similar disproportion as an adult, and a discrepancy in leg length of about three inches will result.

Growth of the tibia in these patients is also often depressed, and the delay in appearance of the secondary centres of ossification of this bone suggests that this is a congenital disturbance rather than shortening due to disuse. The disturbance of growth in the tibia does not contribute materially to the overall inequality except when there is an associated congenital defect of the fibula.

In the present series shortening has not exceeded three inches, except in the one patient with an associated absence of the fibula, and the calculation of the shortening to be expected in the patients who are not yet mature suggests that it will not exceed that figure. Details of the measurements, which have all been confirmed radiographically, are given in Table I.

In the small number of adult patients in this series there is no evidence that the deformity of the femur gives rise to any disability apart from that of the shortening. There has been no clinical or radiological evidence of degenerative change in the hip as a result of the persistent lateral rotation. One patient has required supracondylar osteotomy for an excessive genu valgum, but no other secondary deformity has required correction. These patients therefore present primarily as problems of limb inequality.

TREATMENT

One patient with a short femur and congenital absence of the fibula has been treated by amputation through the knee and provision of a prosthesis. Four patients have been subjected to stapling of the knee epiphyses of the longer leg, and one to epiphysiodesis. In none of these patients has complete correction of the shortening been obtained. Although growth is still continuing in two of these patients they are unlikely to achieve equality. Shortening of the longer femur in one adult has produced a satisfactory result.

Lengthening of a congenitally short femur was reported in four patients by Allan (1948). No complication was noted. For more severe defects Ollerenshaw (1925) performed concomitant lengthening of the short femur and shortening of the normal limb. Van Nes (1950) described a rotation-plasty for congenital femoral defects which permits the foot to activate the knee flexion piece of a prosthesis. The present series does not permit any further conclusions about the value of these measures, but the shortening which has been recorded does not

demand the more drastic surgical procedures. In many patients correction of the inequality may be unnecessary or undesirable. For the others, femoral shortening has the advantage of simplicity and reliability, and maintains the normal level of the knee joint. For less severe shortening, stapling may well prove adequate.

SUMMARY

1. Nineteen patients with congenital shortening of the femur without associated coxa vara have been examined and discussed.

2. The diagnosis is made on finding a short, bulky thigh, held in lateral rotation. The radiographs commonly show no abnormality apart from shortening, but delay in ossification of the head of the femur, with lateral bowing and cortical sclerosis of the shaft, are occasionally present. The overall shortening of the limb seldom exceeds three inches.

3. The place of various surgical procedures to control limb length is briefly discussed.

It is a pleasure to express my gratitude to Mr Denis Browne, Mr G. Lloyd-Roberts, Professor J. I. P. James, Mr P. H. Newman and Mr J. A. Cholmeley, who have permitted me to examine and report upon their patients.

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OSTEOTOMY OF THE CALCANEUM FOR PES CAVUS

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Since the publication of my earlier paper (Dwyer 1955) describing the treatment of pes cavus in children by osteotomy of the calcaneum, many more patients have been operated upon and the procedure has been extended to embrace the more severe deformities encountered in older patients. Over five years have now elapsed since the first operation was performed, and the late results indicate that the procedure is sound.

In children pes cavus develops at any time after the age of three, the age of onset depending on whether the condition is idiopathic or neurological in origin. In the earlier stages what is little more than a high arch is well controlled by a metatarsal bar, but in many cases the deformity progresses to embrace the following characteristics: 1) dropping of the forefoot; 2) contracture of the plantar fascia; 3) clawing of the toes and callosity formation; 4) the gradual development of a varus deformity of the heel and forefoot.

It should be appreciated that, contrary to some text-book descriptions and as pointed out by Todd (1935), contracture of the calcaneal tendon is not a usual accompaniment of uncomplicated pes cavus; equinus is confined to the forefoot, and the heel is usually well developed.

Operations such as those described by Steindler (1921), Lambrinudi (1932), Todd (1935) and others for the relief of pes cavus have, on the whole, proved disappointing, especially for well established deformity in adolescents (Fig. 1).

FIG. 1

Pes cavus in a patient aged twelve, two years after a Steindler operation.

Whatever the underlying etiology, it is certain that, with the onset of varus, the deformity rapidly becomes worse. With adduction of the heel three deforming influences appear. First the calcaneal tendon becomes an active invertor and, since its pull is concentrated largely on the inner border of the heel, much of its force is transmitted to the thick medial portion of the plantar fascia (Fig. 2). In consequence the forefoot is pulled towards the heel. Secondly, the child walks on the outer border of the foot, thus increasing the varus deformity.

Finally, with the heel in varus, weight bearing fails to stretch the plantar fascia and contracture results. The operation that I have described aims at overcoming these deforming influences by shifting the heel into valgus and allowing weight bearing to produce correction.

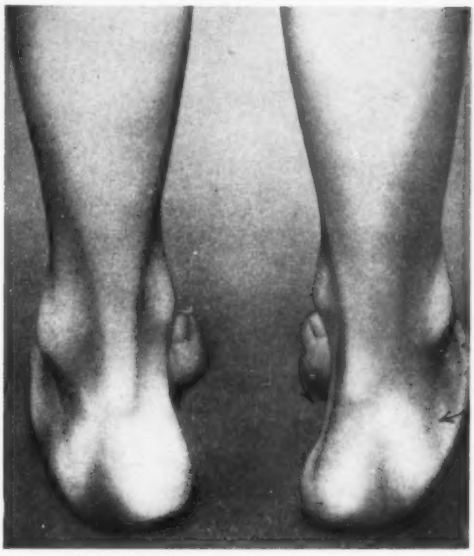

FIG. 2

With inversion of the heel, weight bearing and the pull of the calcaneal tendon become deforming forces, allowing the plantar fascia to contract with resultant approximation of heel and forefoot.

THE OPERATION

First the plantar fascia is divided subcutaneously to reduce the obvious dropping of the forefoot. The outer aspect of the calcaneum is then exposed through a curved incision and the whole flap turned forwards until the tendon of the peroneus longus muscle is exposed. The upper and lower surfaces of the bone are cleared. A wedge, with its base eight to twelve millimetres in width, is removed from the calcaneum just below the peroneus longus, which is used as a guide (Fig. 3). This wedge tapers down to the medial cortex, which must be broken to ensure complete closure of the resulting gap. Pressing the forefoot up into dorsiflexion against the pull of the calcaneal tendon brings the bony surfaces together nicely. Failure to obtain closure is invariably due to leaving a small piece of the apex behind. (It is important

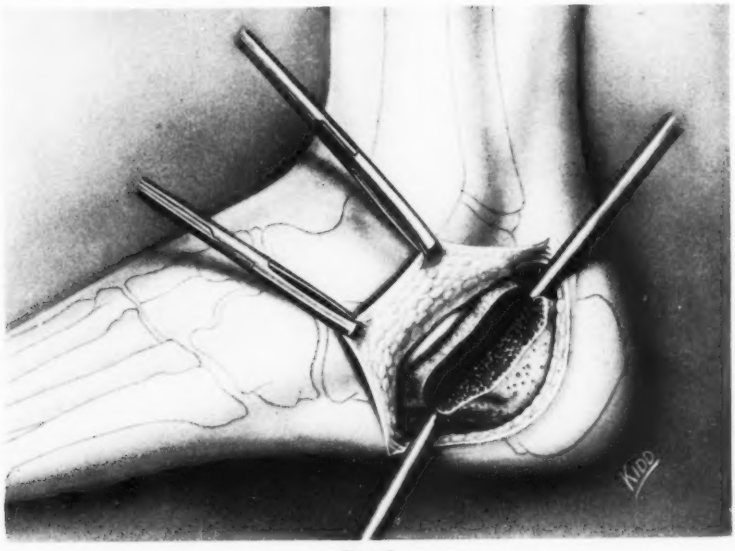

FIG. 3

Technique of operation. A wedge is removed from the lateral aspect of the calcaneum. The osteotomy is made just below the peroneus longus tendon and the posterior talo-calcaneal joint. The medial cortex must be cracked to allow the distal fragment to close easily.

FIG. 4
Case 1—Pes cavus with early varus deformity complicating poliomyelitis in a boy of five.

FIG. 5
Case 1—Nine months after osteotomy of left calcaneum. Heel deformity corrected and arch lower.

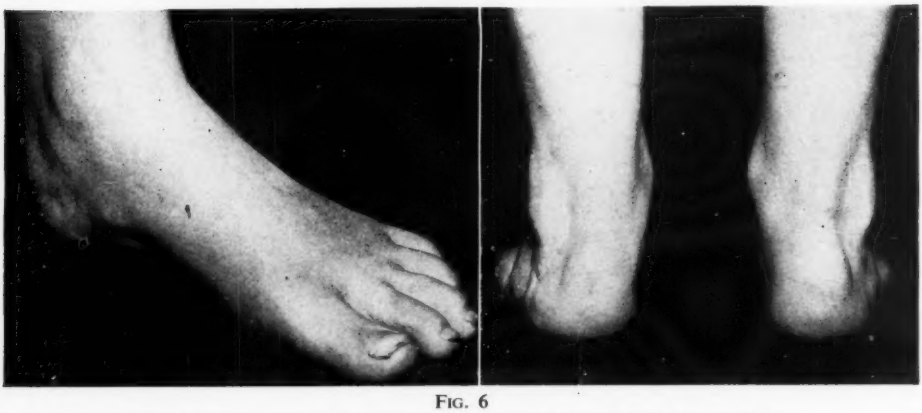

FIG. 6
Case 1—Three years after operation. Foot virtually normal and toes straight.

FIG. 7
Case 2—Deformity of foot in a boy of six, three years after accidental division of both peroneal tendons and a year after transplantation of tibialis anterior to base of fourth metatarsal.

FIG. 8
Case 2—The same foot a year after removal of a lateral wedge from the calcaneum.

at this stage to be sure that the varus deformity has been properly corrected and that the heel is in a neutral or even slightly valgus position.)

DISCUSSION

An early effect of the operation is that walking and shoe wear are remarkably improved. With the varus deformity of the heel corrected, the forefoot gradually follows and the whole foot becomes plantigrade. With certain exceptions that will be mentioned later, relapse is rare and steady improvement takes place provided that the heel has been fully corrected (Figs. 4 to 12).

The principle underlying this type of correction was well illustrated in a boy of three, first seen eight months after irreparable division of both peroneal tendons. Transplantation of the tibialis anterior to the base of the fourth metatarsal two years later, when varus was already well established, failed to halt the progress of the deformity, which was severe at the age of six (Fig. 7). Osteotomy of the calcaneum was performed, and, with the heel squarely on the ground, progressive improvement took place with weight bearing (Fig. 8).

FIG. 9

Case 3—Recurrent cavo-varus deformity in a boy aged twelve, two years after the performance of a Steindler operation. (Same patient as in Figure 1.)

FIG. 10

Case 3—The same patient four years after wedge osteotomy of the calcaneum. The toes were not operated upon, and correction of the clawing has been brought about simply by weight bearing after correction of the heel.

Failure to correct fully the varus deformity of the heel will inevitably lead to recurrence or progress of the initial deformity (Fig. 9), and this explains the high incidence of recurrence after the older types of operation.

Since it was first performed in May 1952 this operation has now been undertaken sixty-three times in forty-one children aged from three to sixteen years. In all the patients the improvement, not only in gait and shoe wear, but also in the dropping of the forefoot and clawing of the toes, has been striking. The early promise has been so well fulfilled by the passage of time that it seems unnecessary to perform any other operation for established pes cavus. In patients presenting early with a high arch only and no varus of the heel, a plantar fasciotomy alone is indicated.

In a few cases it has been necessary to repeat the operation either because complete correction was not obtained at the first operation or because of real recurrence. The reason for recurrence may in some instances be the primary tendency, but muscular imbalance seems to be an important cause because it is particularly in cases of poliomyelitis and spina bifida that one encounters such recurrence. This was well illustrated in a patient of seven, with

FIG. 11
Case 4—Severe deformity of feet in a girl of sixteen.

FIG. 12
Case 4—Two years after correction of the varus of the heel together with multiple filleting and arthrodesis of the toes.

marked varus of the heel after poliomyelitis. Good correction was obtained but, two years later, a second osteotomy was necessary because varus had recurred and, even after that, there was further recurrence, which was dealt with by transplanting the tibialis anterior to overcome the relative weakness of the evertors.

Recurrence occurred also in one patient with spina bifida who suffered infection of the calcaneum after the operation. A persistent sinus cleared up after removal of a sequestrum. There was then still some varus of the heel and it was rather small and did not come properly to the ground. Three years after the original operation the varus deformity was corrected by inserting a bone wedge into the inner side of the calcaneum, which had the effect of increasing the height of the heel and at the same time improving the deformity.

In six heels the operation was repeated at an interval varying from six to eighteen months after the original operation because there was some varus deformity, probably because the initial wedge had been too narrow.

Even in older children, with well established bony deformity of the forefoot, quite appreciable flattening of the longitudinal arch can be demonstrated some time after correction

of the heel (Figs. 11 and 12). The degree of correction seen in Figure 12 is better than average, and the extent of falling of the arch which takes place depends on the age at the time of operation and on the strength of the bones. In boys, with rather stronger bones than in girls, one does not expect to see so much change in the cavus element. Nevertheless correction of the heel overcomes the important problem of excessive wear of the outer sides of the shoes, and also allows the toes to straighten out if they are malleable. The subjective improvement is much greater than the objective because the feet are properly balanced.

In patients with pes cavus one seldom encounters real contracture of the calcaneal tendon. If such contracture is present it must be dealt with first by a separate operation, before correction of the cavus deformity.

In adults with a high fixed arch, gross varus of the heel and forefoot and clawing of the toes, good correction can be obtained by the same means. A large lateral wedge is removed from the heel to correct inversion, and the plantar fascia is divided. The dropped and distorted forefoot can then be brought up to full correction by taking an appropriate wedge from the tarso-metatarsal region. It must be appreciated, however, that to achieve sound fusion at this site takes a good deal longer than is the case with a mid-tarsal wedge. This is a small price to pay for preservation of mid-tarsal-subtalar movement.

SUMMARY

1. A new surgical approach to the treatment of pes cavus is suggested. The operation consists in a subcutaneous division of the contracted plantar fascia and correction of the varus deformity of the heel by removing a wedge from its lateral aspect. It is submitted that, by approaching the deformity from behind and overcoming the varus of the heel, the foot is rendered plantigrade and that thereafter weight bearing exerts a corrective influence which results in progressive improvement of the deformity. The operation is essentially a prophylactic one and, for the best results, it should be performed before there is gross structural deformity and while active growth is still taking place.

2. Even in patients over the age of fourteen, improvement is obtained by doing nothing more than this simple operation. In the presence of fixed deformity of the forefoot, as encountered in older patients, inversion is corrected by removing a lateral wedge from the calcaneum and the cavus by taking a dorsal wedge from the tarso-metatarsal region. This has the double advantage of producing good correction of deformity, while at the same time preserving movement at the mid-tarsal-subtalar joint. Fixed clawing of the toes will require appropriate corrective treatment, but if the toes are malleable the simple effect of weight bearing on the plantigrade foot produces gradual correction.

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LUMBO-SACRAL INTER-BODY SPINAL FUSION

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During the years from 1948 to 1956 a lumbo-sacral inter-body spinal fusion was done on forty-eight patients through a posterior approach. The operations have been divided chronologically into three groups. Improvements in the surgical technique were added in the two later groups, so that ultimately a new operative procedure was evolved and used in the last group, which gave the highest rate of bony fusion.

In this new operation the lumbo-sacral intervertebral disc is approached through the lateral mass of the sacrum, which gives a good exposure through which to perform the inter-body fusion. It must be emphasised that this operation was developed not only from the personal experience of the author but also from reports and advice from other workers such as James and Nisbet (1953), Cloward (1953), du Toit (1955), du Toit, Dommisse and Muller (1956) and du Toit (1957).

PRINCIPLES OF THE OPERATION

Through a mid-line incision, extended distally as far as the third or fourth sacral spinous process, the sacro-spinalis muscle mass is exposed and retracted laterally on each side; the laminae and paravertebral joints are exposed by cleaning off all muscle and fascia.

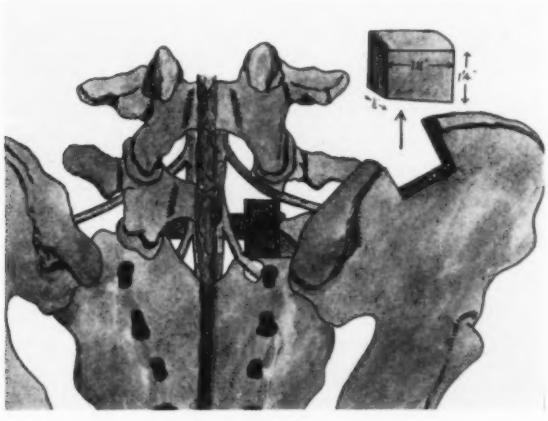

Fig. 1

A diagram of the trans-sacral approach. Both sides are grafted but for clarity only one side is shown exposed.

Figure 1 is a diagram of the operation: for clarity it shows the graft on one side only. Both sides must be grafted for a successful fusion, which involves only the two adjacent vertebrae. Since the grafts are horizontal they are compressed by the vertical thrust of the body weight, and shearing strain is eliminated (Fig. 2).

The shearing angle at the lumbo-sacral level, which is increased in spondylolisthesis, can be reduced only if the bed for the graft is cut horizontally, as shown in Figure 2, to pass obliquely through the intervertebral disc.

Shearing strain is thought to have been the most important factor in causing the complete absorption of the grafts in the past, a phenomenon that has probably been observed by other workers in this field.

The graft must have the greatest possible contact with the graft bed and this is an important detail in helping to ensure fusion (Fig. 3). Each graft has a surface area of about half a square

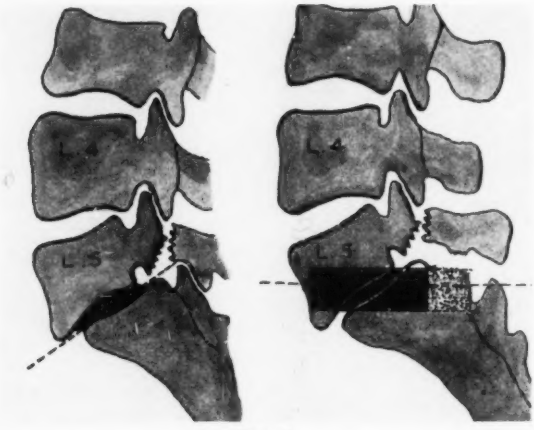

FIG. 2

The horizontal position of the grafts is shown. The grafts are thus at right angles to the line of thrust which the body weight imposes.

inch, whereas that of a vertebral body is two to three square inches. When the graft is deeply countersunk, as shown in Figure 4, the sides form additional contact surfaces and double the contact area between the graft and the bed.

It is necessary to insert the two grafts in an antero-medial direction, so that they converge towards the centre of the anterior surface of the vertebral body. This not only assures the

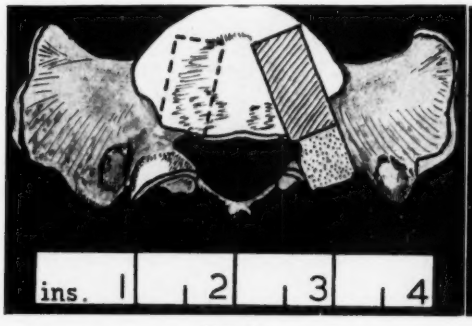

FIG. 3

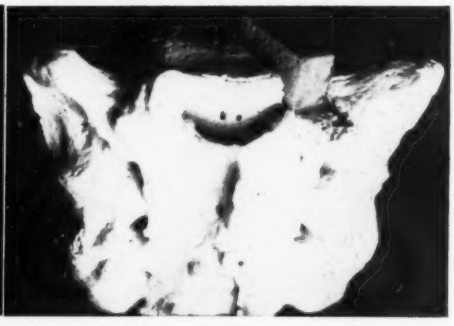

FIG. 4

Figure 3—The relative sizes of the two bone grafts to the vertebra can be seen. Deep countersinking of the grafts increases the area of contact. Figure 4—A macerated specimen of a sacrum, showing how the graft is deeply countersunk.

greatest penetration of the bodies by the grafts, but also eliminates the risk of perforating the visceral cavity or injuring the great vessels. The grafts, being locked together in the form of an inverted V in the deep grooves in which they lie, are secure against shift and shear in both horizontal and perpendicular planes.

OPERATIVE TECHNIQUE

1. The general anaesthetic is chosen with care and, to prevent accumulation, a carbon dioxide absorber is used. The patient is placed prone on a Wilson frame in such a position to lessen pressure on the thoracic and abdominal viscera and so diminish bleeding. A blood transfusion, usually of two to three pints, is given routinely during the operation.

2. Through a posterior mid-line incision the laminae and articular facets in the lumbo-sacral region are bared and the first sacral nerve root is exposed by excision of the inferior articular facets and the distal half of the lamina of the fifth lumbar vertebra as well as the proximal quarter of an inch of the first sacral lamina on each side.

3. The fifth lumbar nerve roots are exposed in the intervertebral foramina by removing all, or as much as necessary, of the superior articular facets of the first part of the sacrum. Great importance is laid on the very wide exposure of the nerve roots (Fig. 5), and this is the key to a successful operation.

4. The superior surface of the lateral mass and body of the sacrum is channelled (Fig. 6) in an antero-medial direction obliquely between the exposed nerve roots.

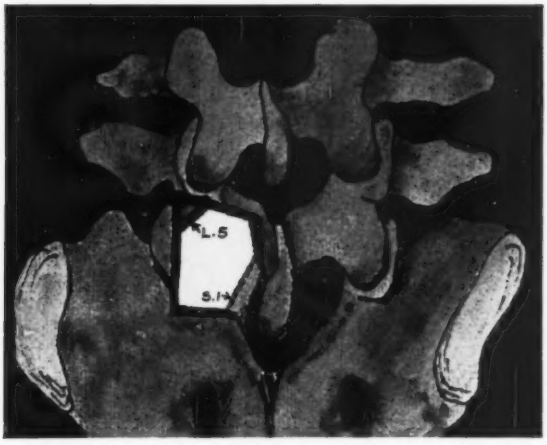

FIG. 5
A diagram showing how excision of the inferior articular facet of the fifth lumbar vertebra and most of the superior facet of the sacrum exposes the nerve roots.

5. The intervertebral disc is undermined and the deep grooves are completed in the adjacent surfaces of the first sacral and fifth lumbar vertebrae, which now form the box-shaped beds for the bone grafts (Fig. 7). Special instruments have been made for this step in the operation, and the du Toit box-shaped osteotome is used as a starter (Fig. 8). Curved U-shaped osteotomes are used to finish cutting the graft beds (Fig. 9). They are designed to accommodate the posterior iliac crest and the sacro-spinalis muscle mass so that they can be inserted in the antero-medial direction as shown in Figure 3. A complementary pair of these instruments is needed for the upper and lower surfaces of the bed for the graft. The smooth sides of a special bone graft introducer (Fig. 10) prevent the rough edges of the graft from catching and damaging the delicate tissues around the graft bed.

6. Two grafts, either homogenous or autogenous, and usually from the iliac crest, are prepared to fit accurately into their respective beds.

7. With the spine slightly flexed the grafts are hammered firmly into position, and it is necessary to ensure that impaction of the second graft does not cause retropulsion of the first.

FIG. 6

FIG. 7

Figure 6—The intervertebral disc has been undermined. The fifth lumbar nerve root is conspicuous in the top left hand corner, and the first sacral on the right. Figure 7—The bed for the graft has been completed on one side.

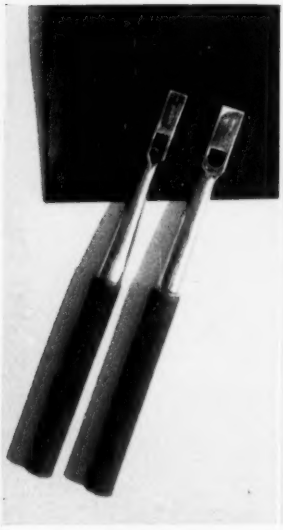

FIG. 8

FIG. 9

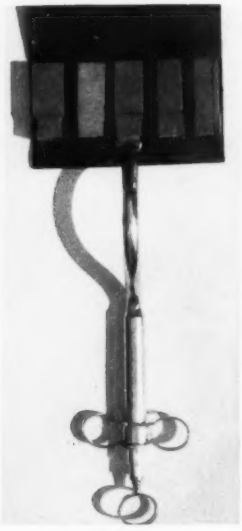

FIG. 10

Figure 8—J. G. A. du Toit's box-shaped osteotomes, used at the start of cutting the cavities for reception of the grafts. Figure 9—The author's curved, U-shaped osteotomes, used for completing the beds for the grafts. Figure 10—The author's bone graft introducer. The interchangeable end-pieces are in six sizes.

Careful adjustment of the direction in which the bed for the second graft is cut eliminates this small difficulty.

8. Both grafts are made so that they are countersunk below the level of the posterior surfaces of the vertebral bodies; the spine is then extended. This causes firm compression of the grafts. It is of interest that slight retropulsion of the grafts may be seen if the spine is

flexed at this stage, emphasising the importance of avoiding flexion in the post-operative period.

9. Two weeks after operation a short single plaster hip spica is applied to prevent flexion at the lumbo-sacral angle. The patient is kept in bed for three months.

RESULTS

Of the thirty-two patients who had homogenous bone grafts foreign body reaction, with fibrous tissue barrier formation, was seen in nine (28 per cent). This barrier may develop between the whole or only a part of the graft and the host; this has not been observed in any of the sixteen patients who had autogenous grafts, and the speed of incorporation of the latter was also considerably faster than that of the homogenous grafts.

TABLE I

RESULTS IN PRESENT SERIES

Clinical assessment	Number of patients	Per cent
Very good and good	39	81
Improved	5	11
No change	1	2
Worse	2	4
Untraced	1	2
Total	48	100
Radiological assessment		
Fusion present	24	50
Fusion absent	20	42
Undetermined	4	8
Total	48	100

The results in this series are shown in Table I. The results of other workers are summarised in Table II. This shows that good clinical results were obtained in over 74 per cent (and in one series in 100 per cent) but that fusion occurred in as little as 1·5 per cent in one series and as many as 98·5 per cent in another. Variations in operative technique render further comparison of little value.

TABLE II

RESULTS IN PUBLISHED SERIES

Author		Jaslow 1946	Cloward 1953	Adkins 1955	Nisbet and James 1956	Wiltberger 1957
Number of patients		27	321	70	19	46
Bony union	Total	?	315	1	8	40
	Per cent	?	98	1·5	42	87
Clinically cured or improved	per cent	100	85	approx. 77	74	87

Of the forty-eight patients in the series twenty-nine were men and nineteen were women. Thirty-five patients had spondylolisthesis or spondylolysis and the remainder suffered from spinal instability either associated with disc lesions or following unsuccessful disc surgery.

The average age was thirty-five; the youngest patient was fifteen and the oldest fifty years of age. There was no selection: all patients subjected to this type of operation during the period under review are included. The longest follow-up is nearly ten years, the shortest seventeen months and the average is exactly four years.

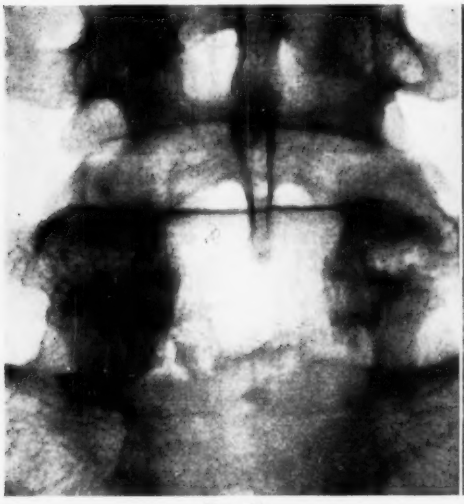

FIG. 11

FIG. 12

Figure 11—Successful inter-body fusion clearly shown on an antero-posterior film. Figure 12—An unsuccessful inter-body fusion which clearly shows the pseudarthrosis.

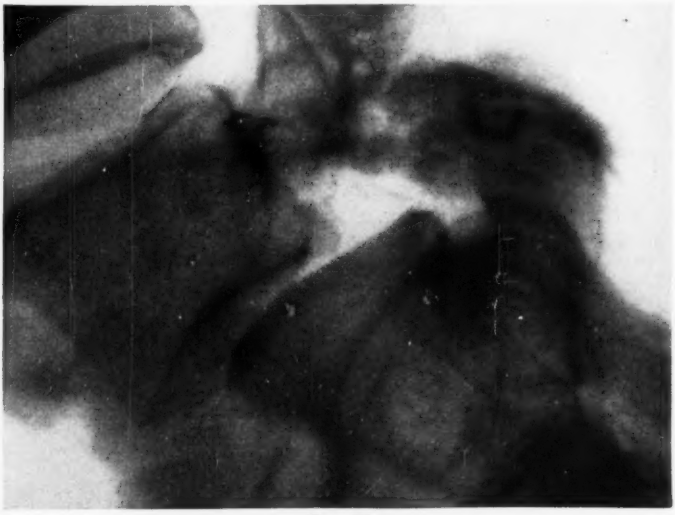

FIG. 13

The pre-operative radiograph of a patient with spondylolisthesis. The defect in the pars interarticularis shows well.

It must be emphasised that the 42 per cent of unsuccessful fusions included the *early* failures, and the percentage of successful fusions increased to 76 per cent in the final group of twenty-four patients.

FIG. 14

The same patient as in the last illustration ten months after fusion. Some change can be seen in the defect in the pars interarticularis.

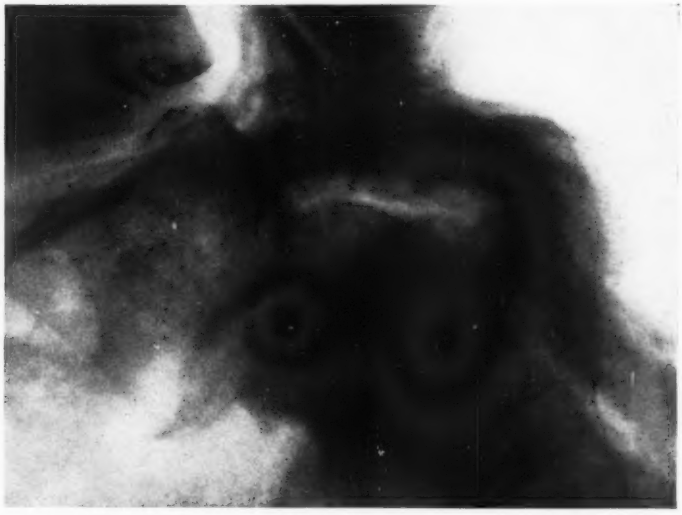

FIG. 15

The same patient as in Figure 14. The defect in the pars interarticularis appears ossified, and sound inter-body fusion is present.

DISCUSSION

Adkins, in 1955, believed that " some intrinsic factor peculiar to the vertebral bodies " militates against successful inter-body fusion. This has not been my experience, for bony union between vertebral bodies has been seen after fractures, after sepsis following removal of a disc and after inter-body grafting.

The assessment of bony fusion has been based on radiological appearances which,

although difficult and inaccurate, must suffice for lack of a better method. There was, however, one patient in whom the opportunity occurred of doing a biopsy on the site of a graft performed ten months earlier. In this patient radiological assessment showed a failure of union; yet microscopical examination revealed evidence of sound fusion and of the presence of living bone indistinguishable from the host bone. Radiological examination after a further ten months corroborated these findings.

The success of spinal fusion is best shown radiologically in antero-posterior views and in lateral views in flexion and extension. Absorption of the grafts and replacement by visible new bone, the absence of encapsulation or sequestration of the grafts, and failure to demonstrate mobility on flexion and extension of the spine are the most important radiological features, all of which must be present before a successful fusion may be claimed. The appearance of a successful fusion is shown in Figure 11.

Failure of spinal fusion is much more easily recognised, and in some of the patients under review there has been complete absorption of the grafts. In others the grafts have become encapsulated and have remained unchanged, without improvement of the spinal instability. In yet other patients a pseudarthrosis has developed which is easily recognised radiologically (Fig. 12).

FIG. 16

FIG. 17

FIG. 18

Figure 16—This professional wrestling champion (on top in this picture) had an inter-body fusion nine years previously. Figure 17—Building his own house, this man is lifting a concrete block weighing 67 pounds five years after his inter-body fusion. Figure 18—This patient can " touch his toes backwards " five years after the operation.

The progressive ossification of the defect in the pars interarticularis in three patients with spondylolisthesis has recently, and quite unexpectedly, been suggested in the radiographs taken at intervals after operation. In none of the three was the pars interarticularis disturbed at operation, which resulted in bony fusion in each patient. Figures 13 to 15 show the radiological changes in one of these patients.

Although healing of the defect in the pars interarticularis does not seem to have been described before it would be premature to comment on the significance of these findings, but a similar ossification was not seen when the inter-body fusion failed. Perhaps the defect in the pars, if it is in the nature of a stress fracture, might be capable of healing when the strain is removed.

Complications—The complications that occurred in this series were: 1) Fusion failed to occur in twenty patients (42 per cent), but the incidence of failure dropped to 26 per cent in the final group. 2) Retropulsion of the grafts occurred in three patients (6 per cent). 3) Foot drop occurred in two patients (4 per cent). The cause of this is not clear, but it was seen only when a revision operation was performed for failure of fusion or some other complication; there is some evidence that a segmental thrombosis of the spinal vessels occurred after the second operation, and this is supported by the permanent nature of the lesion. 4) Sepsis occurred in only one patient and has proved intractable. This patient is one of the two mentioned with a permanent foot-drop. 5) A pulmonary embolus occurred in one patient and a venous thrombosis in another, but both made a complete recovery. Transitory bowel and bladder complications occurred frequently. There were no deaths in the series.

CONCLUSIONS

This review shows that inter-body spinal fusion can be achieved in a satisfying percentage of cases, and the assertion that there is an intrinsic factor peculiar to the vertebral bodies which prevents such a fusion cannot be supported. The operation has a limited but definite place in the field of spinal surgery, and should be reserved for those patients with spinal instability associated with intractable and persistent backache. Spondylolisthesis is the indication *par excellence*. A new operative technique, which has been developed during ten years, has become standardised. The trans-sacral approach provides a better and safer exposure than those described before. In the event of failure of inter-body fusion, it is suggested that further attempts at grafting should be restricted to one of the posterior methods which have a 75 per cent chance of producing successful bony fusion.

Clinical photographs are reproduced in Figures 16 to 18 to show that patients suffering from a painful spondylolisthesis may be restored to normal activity by this operation.

I wish to thank Mr G. T. du Toit for his great help and Mr J. G. du Toit for special instruments; Drs F. W. McLachlan, A. v B. Smith and A. C. Macdonald for their untiring co-operation in obtaining radiographs; Professor C. J. N. Loubser for his assistance; and Professor J. F. Barnetson and Mr J. G. de Swardt for their advice on pathological examinations.

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OBSERVATIONS ON THE AMBULANT CORRECTION OF THORACIC SCOLIOSIS AND KYPHOSIS WITH PARTICULAR REFERENCE TO THE EXPERIMENTAL USE OF HYDROSTATIC PRESSURE

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This communication is a preliminary report of a method of correcting spinal deformity in the thoracic region by means of an ambulant plaster jacket. No attempt is made to discuss either indications for correction or subsequent management after correction.

The clinical material has consisted of cases of idiopathic thoracic scoliosis and adolescent kyphosis (Scheuermann's disease) in which correction was considered necessary. As the problems differ, scoliosis and kyphosis will be considered separately.

THE PROBLEM OF CORRECTION IN THORACIC SCOLIOSIS

There are two elements of deformity in idiopathic scoliosis: lateral curvature and vertebral rotation. The latter is largely responsible for the rib-hump which is the most disfiguring element. The ideal method of correction must therefore aim to correct rotation as well as lateral curvature; this implies the application of a side-bending force to correct the lateral curvature and adequate pressure to the rib-hump to act indirectly on the spine, using the ribs as lever arms, to produce derotation. Forces required to correct a fixed scoliosis are considerable, and the chest-spine complex provides a difficult surface for the application of a sufficient force which is at the same time within the limits of skin tolerance. This is particularly true of any direct attempt to correct rotation.

Corrective methods in common use—The several types of corrective plaster jackets in common use in this country are based on the principles of Abbott (1912, 1917), Risser (Hibbs, Risser and Ferguson 1931) and Stagnara and Queneau (1953). The Abbott jacket aims to correct both deformities, but the apparatus required to apply it is extensive, and the insertion of felt pads to bring pressure on the rib-hump is clinically difficult and inaccurate. It does not seem to be widely used now, because of these practical difficulties. The Risser turnbuckle jacket, probably most widely used at the present time, makes no attempt at direct correction of rotation, and therefore cannot be considered ideal. The Stagnara vertical distraction jacket requires very careful application and supervision if skin sores are to be avoided, although it may have a particular indication in the management of the high thoracic curve when other methods are not applicable.

A conviction that none of these methods adequately fulfilled the theoretical requirements led to a search for some new technique.

Practical requirements for optimal correction—If adequate pressure, for an adequate period, is to be maintained on the rib-hump to effect reduction of rotation, the following conditions must be fulfilled: 1) Even distribution of pressure over the irregular surface of the rib-hump to generate the considerable pressure necessary without production of skin damage. 2) Capacity of the pressure-producing agent to expand, so that continuous pressure may be maintained as the rib-hump is flattened. 3) A degree of elasticity, while maintaining pressure, to accommodate respiratory movement and to allow for change in shape as correction progresses. 4) Ambulation should be maintained not only to preserve the general well-being and morale of the patient but also because exercise will encourage vigorous active chest movement to push against the corrective force and thus aid reduction—a point stressed by Abbott (1912, 1917), by Aitken (1928) and, more recently, by Stagnara and Queneau (1953).

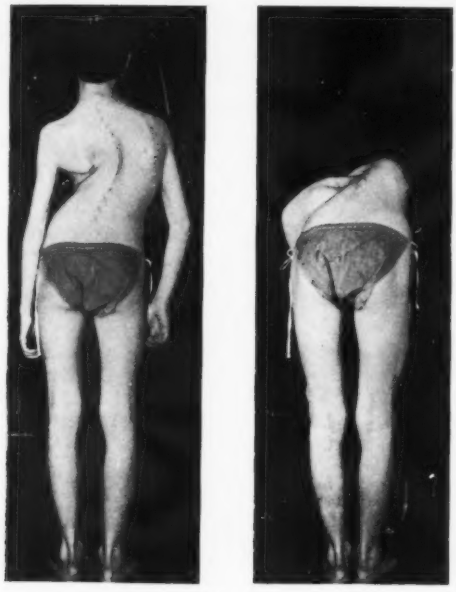

FIG. 1

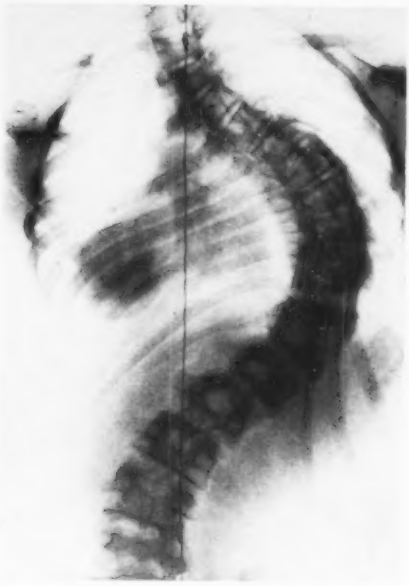

FIG. 2

Case 1. Figure 1—A thirteen-year-old girl with idiopathic scoliosis and a prominent rib-hump. Figure 2—A radiograph taken in full right flexion and showing only 10 degrees of correction.

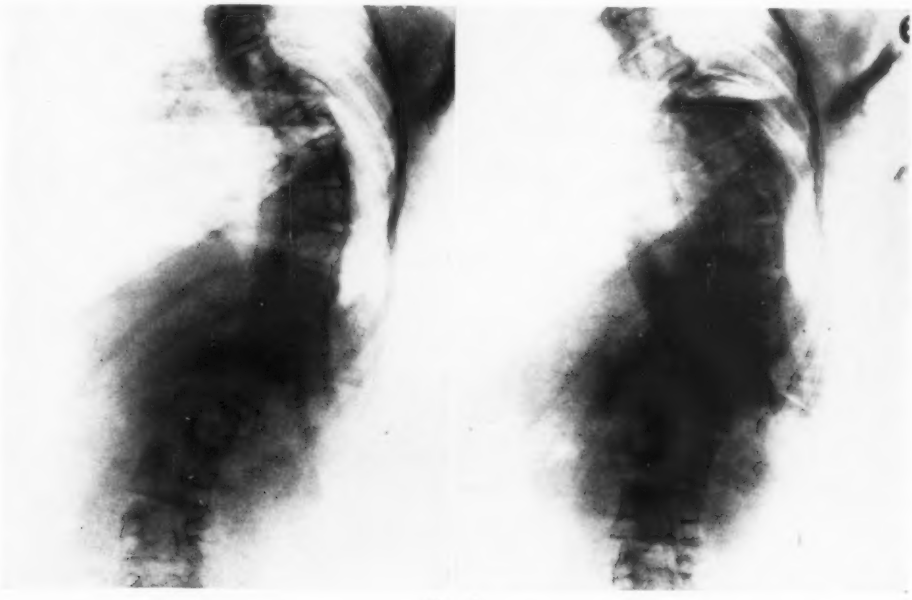

FIG. 3

Case 1—The correction of the scoliosis shown in the preceding figures. *On the left* correction to 63 degrees has been obtained by Oswestry jackets; and the further correction to 45 degrees by means of a hydrostatic bag is shown *on the right*.

A consideration of these requirements at once emphasises the fundamental unsuitability of any rigid mechanical system for correction, and suggests the use of fluid in a semi-elastic container, such as water in a suitable rubber bag, as the pressure-producing agent. This gives the possibility of automatic pressure distribution and perfect congruity and adaptability of shape, with the production of high and controlled elastic pressure by the addition of water under pressure.

FIG. 4
The Oswestry jacket, modified from that of Risser, after incorporating a hydrostatic bag. The nozzle can be seen in the posterior view on the right of the jacket.

Clinical application of these principles—The " hydrostatic bags " used clinically have been made simply from a rugby football inner bladder, encased in stockinette to limit expansion in unwanted directions, and the whole sandwiched between thin felt to avoid rough edges and to allow free expansion. A ball-valve nozzle is securely attached, through which water under pressure may be added from a metal pump. Lateral correction is obtained by the use of a modified Risser jacket of the Oswestry pattern. This differs from the original in obtaining correction by multiple wedging instead of by hinges and turnbuckle, and in leaving the leg free. This type of jacket has been used at the Robert Jones and Agnes Hunt Orthopaedic Hospital for many years, and is considered to be as effective as the original in correction, with certain advantages, including the possibility of ambulation (Fig. 4).

One patient is described in detail to illustrate the method in clinical use.

CASE REPORT

Case 1—A girl aged thirteen had a severe and progressive idiopathic scoliosis, with a virtually fixed primary curve of 98 degrees, measured from the fifth thoracic to the first lumbar vertebra (Fig. 1). Full contralateral flexion gave a correction of only 10 degrees (Fig. 2). The fullest possible correction was obtained by a series of Oswestry jackets. When the safe limits of the method were considered to have been reached, correction to 63 degrees had been obtained (Fig. 3). An aperture was now cut in the plaster over the rib-hump and a hydrostatic bag applied over a thin layer of sponge rubber. The

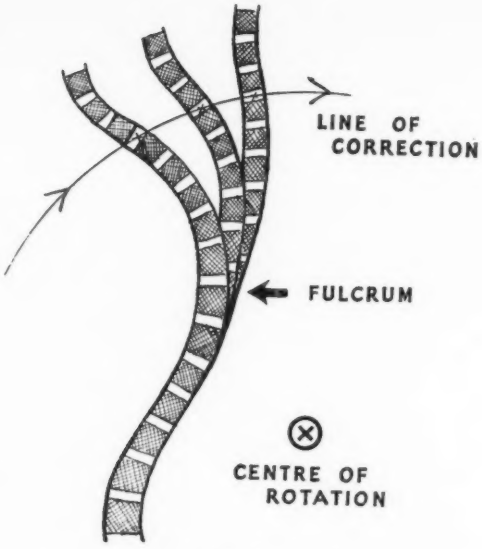

FIG. 5

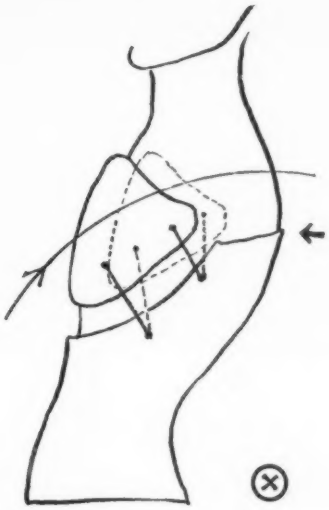

FIG. 6

Figure 5—The line of force required to correct a thoracic kyphosis is curved. Figure 6 shows how this force may be applied in practice by hinging the breast-plate with cord or chain.

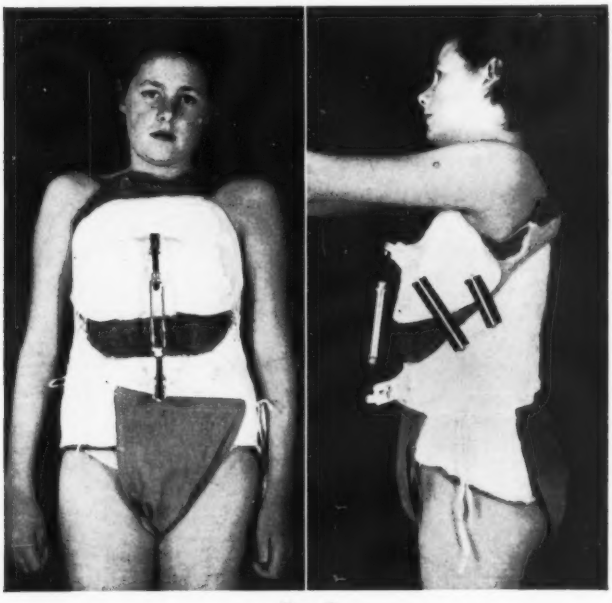

FIG. 7

The practical application of a jacket giving a true corrective force in a girl with a thoracic kyphosis.

plaster was now reconstituted over the apparatus, leaving the nozzle protruding (Fig. 4). Twice daily water was added under pressure within the comfortable tolerance of the patient, who remained ambulant throughout.

The result after one month is shown in Figure 3; further correction to 45 degrees has been obtained and, as a certain amount of direct reduction of the rib-hump has been produced by a true derotation, it is suggested that the cosmetic improvement is greater than would be expected from a similar correction achieved by lateral flexion alone, if indeed such were possible.

There has been no trouble from skin pressure using this technique, and it seems to provide a safe, accurately controlled and practical method to increase the correction by a direct attack on the rotatory element of deformity in idiopathic thoracic scoliosis.

THE PROBLEM OF CORRECTION IN THORACIC KYPHOSIS

From the mechanical point of view, in the ambulant patient, a true corrective force can be brought to bear on the kyphotic spine only by a backward and upward pressure on the upper curve, working against a fulcrum at the point of greatest deformity. The line of force

FIG. 8

This radiograph of the girl shown in Figure 7 was taken before treatment. Compare with Figure 9.

required will be a curve (Fig. 5). In practice, of course, the force must be applied indirectly through the sternum and ribs. This introduces difficulties because the ribs tend to bend.

Methods in use for the attempted ambulant correction of adolescent thoracic kyphosis—Fixed spinal supports of the classical Thomas pattern or its many modern derivatives may do something to prevent the increase in deformity, but cannot in the true sense be regarded as

corrective. Plaster jackets of the Telson type, attempting to gain correction by purchase through straps on the shoulder girdle, are unlikely to be effective in producing true correction because sufficient pressure cannot be taken by the axillae. Correction, such as it is, is more apparent than real, due to the camouflaging effect of pulling back the shoulders. Wedged or laterally hinged plaster jackets cannot apply an ideal corrective force because no hinge point available can produce the required line of force (Fig. 5).

A rigid mechanical method of producing corrective force in the required axis—By employing a completely detached breast-plate, anchored to the body of the plaster by a pair of radius arms (in practice strong cord or light chain) to convert the push of an anterior turnbuckle into an upward and backward curvilinear force, something approaching the proper direction of application of force can be achieved (Fig. 6). Such an apparatus in clinical use is shown in Figure 7. True correction can be gained by this method. The correction gained in the case illustrated is shown in Figures 8 and 9. Measuring the curve from the fifth to the twelfth thoracic vertebra shows a correction from 50 degrees to 30 degrees. Certain physiological

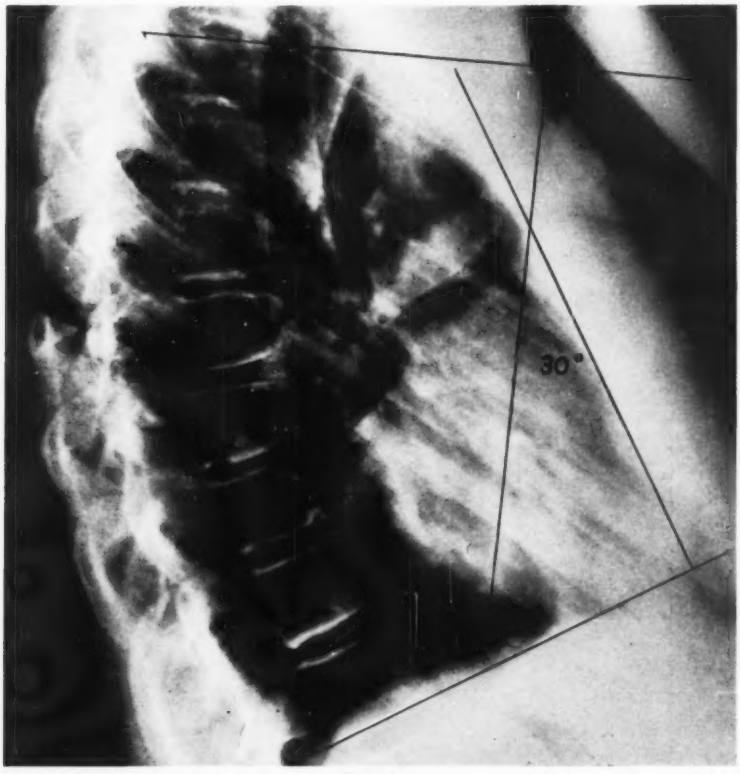

FIG. 9

Radiograph of the same girl after correction. The method produced an improvement of 20 degrees but at the expense of a flattened chest.

difficulties are, however, encountered: 1) The rigid pressure apparatus is uncomfortable, giving the patient a sense of constriction of breathing, and will not be generally tolerated. 2) Considerable flattening of the chest may be caused, emphasising the powerful force that is required to produce true correction. This flattening is clearly shown in the lateral views of the chest in the case illustrated (Figs. 8 and 9). It was felt that such deformity was undesirable

and possibly even dangerous. In order to overcome these difficulties a technique was evolved in which a hydrostatic bag was used as the source of pressure.

Correction of thoracic kyphosis by hydrostatic pressure—The principle of the apparatus is shown in Figure 10. A plaster-of-Paris breast-plate is made, fitting accurately and coming well round the ribs laterally to give support. This is lined with a layer of sponge rubber. A complete plaster jacket is applied over this, with the well padded upper posterior edge opposite the apex of the kyphos, and the hydrostatic apparatus is inserted between the outer jacket and the breast-plate.

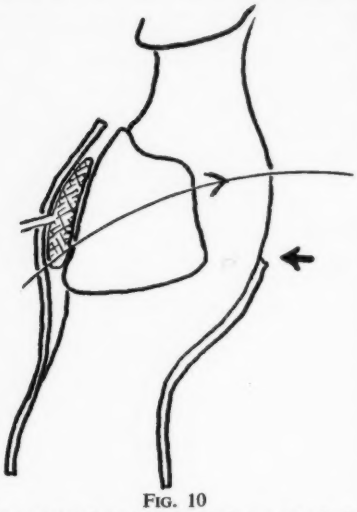

FIG. 10

Principle of the hydrostatic bag method of correcting a thoracic kyphosis.

CASE REPORT

Case 2—A boy aged fifteen has been chosen to illustrate the method in clinical use. He was heavy and well developed for his age, and therefore demonstrates a more difficult mechanical problem than is usually met in these cases. He presented a considerable lower thoracic kyphosis from Scheuermann's disease (Fig. 11). The angle of greatest deformity has been measured over a short segment from the ninth thoracic to the first lumbar vertebra to show the correction that occurred at this site (Fig. 12), where a radiological improvement of 25 degrees has occurred during the four weeks of ambulant treatment (Fig. 13). It is interesting that this boy could not tolerate a previous attempt at correction in a rigid jacket.

The advantages claimed for the method are: 1) True correction can be achieved at the site of primary deformity. 2) The apparatus is tolerated quite comfortably by the patient, although at first sight it is rather bulky. Perhaps due to a certain amount of "give" on respiration there

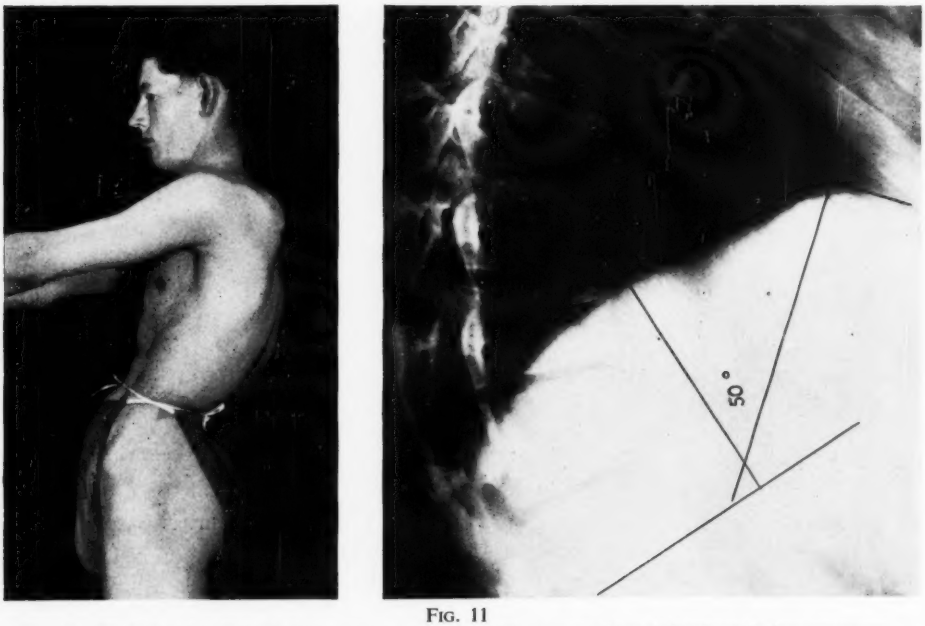

FIG. 11

Case 2—Clinical and radiological appearances of a boy with a severe thoracic kyphosis before treatment.

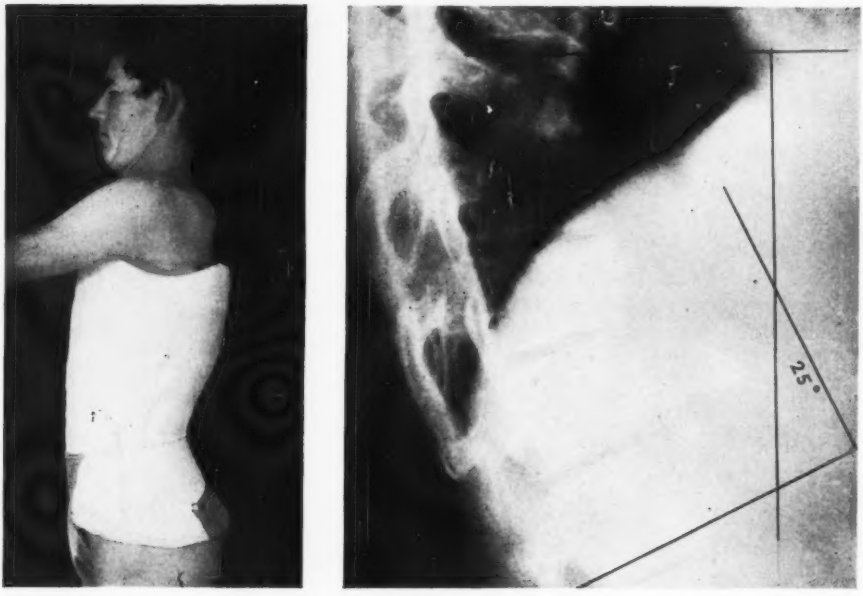

FIG. 12
Case 2—The boy seen in a holding plaster jacket after correction of the kyphosis by 25 degrees.

FIG. 13
Case 2—Photograph of the patient during treatment. The boy was up and about the whole time.

is not the same unpleasant feeling of constriction which is felt with the rigid mechanical system. 3) The floating breast-plate can follow the path of correction accurately, not arbitrarily anchored by hinge or radius arm. Thus pressure is applied to the greatest advantage, and correction can be achieved by a lesser and therefore safer force. Furthermore, hydrostatic pressure is evenly distributed. 4) The breast-plate can be brought well round the sides of the chest to prevent the antero-posterior compression seen in the rigid mechanical method. 5) The patient remains up and about throughout, and could, if necessary, be treated as an out-patient.

CONCLUSION

The apparatus used in these experimental jackets has been of a simple and somewhat crude nature, but the results obtained are sufficiently encouraging to suggest that, with refinements, the principles employed may prove a useful addition to methods at present available for the correction of thoracic spinal deformity.

SUMMARY

1. The theoretical requirements for optimal correction of thoracic scoliosis and kyphosis are discussed, and observations are made on the limitations of methods in current use for their ambulant correction.

2. The experimental use of hydrostatic pressure in an endeavour to satisfy these clinical requirements is described.

3. It is suggested that the use of hydrostatic pressure as the source of corrective force has considerable advantages, and that, with refinements, the techniques described may prove a useful addition to rigid mechanical methods of correction.

My thanks are due to the Consultant Staff of the Robert Jones and Agnes Hunt Orthopaedic Hospital for allowing me to treat patients under their care by these methods, and in particular to Mr Robert Roaf, Director of Clinical Studies and Research, for his interest in this work and for advice in preparing this communication. I also wish to thank Sister H. Arthur and her staff for help in the plaster work and Mr B. Southern for the photographs.

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RESOLVING SCOLIOSIS

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It has usually been accepted as a working hypothesis in scoliosis that, once a curve with structural changes is present in a growing child, it will increase. The extent of the increase will depend on various factors, the most important single one being the length of the growth period still ahead of the patient. In the continuing search for the factors influencing the increase in the deformity it has become evident that things other than growth, and other mechanical factors, influence the behaviour of the curve. Furthermore it has become possible, by careful charting and curve analysis, to give a fairly accurate prognosis in many types of curve. Some of the unknown factors can be exemplified by the markedly different types of curve in poliomyelitis—the paralytic type—and the type which I call " idiopathic " (Figs. 1 and 2). No reliable evidence is available yet as to what is responsible for this strikingly different curve pattern. The conception that once a curve has started it will inevitably increase is the logical conclusion of a mechanical approach to the problem. It might be called the " vicious circle " concept of scoliosis.

In the study of the factors concerned, and the variety of curve patterns and progress, it became evident that this gradual increase with varying speed does not always take place. It was also pointed out (Scott 1956) that there was a high proportion of infants (80 per cent at six months) having a definite lateral curve of 10 degrees or more, that this had decreased without treatment to 7 per cent by eighteen months, and that none of these children had a measurable deformity by the age of two years. This state of affairs was considered to be a natural infantile alignment of the spine, and the disappearance of the curve was attributed to the assumption of the erect posture. A resolving type of infantile scoliosis was also described in which curves of 20 degrees with structural changes gradually disappeared over anything up to four years (Scott and Morgan 1955).

The purpose of this paper is to describe four patients whose curve patterns and progress suggest that " resolving " types may be much more frequent and variable than is at present appreciated.

CASE REPORTS

Case 1—Child born in March 1947. First seen at age six months with curve of 25 degrees. The curve extended from T.6 to T.11 and was convex to the left. He was seen at intervals of six months. The curve remained about the same for three years, and then rapidly decreased. There was no other abnormality to be found, and the child was healthy in every other way (Figs. 3 to 7).

Case 2—Child born in December 1946. A spinal curve was noticed in the nursery. It extended from T.6 to T.11 and was convex to the left. The child was otherwise normal, and there had not been any abnormality in pregnancy or delivery. The curve has gradually decreased from 48 degrees at the age of two to 10 degrees at the age of eleven (Figs. 8 to 12).

Case 3—Child born in January 1950. Seen at age one month. There was a congenital abnormality of both arms, with partial absence of the left humerus and dislocation of the head of the right radius. A lateral curve of the spine was first present at eighteen months. It extended from T.6 to T.12 and was convex to the left. There was no evidence of a congenital abnormality of the spine. After remaining about the same till the age of five the curve gradually decreased, and at the age of eight has virtually disappeared (Figs. 13 to 17).

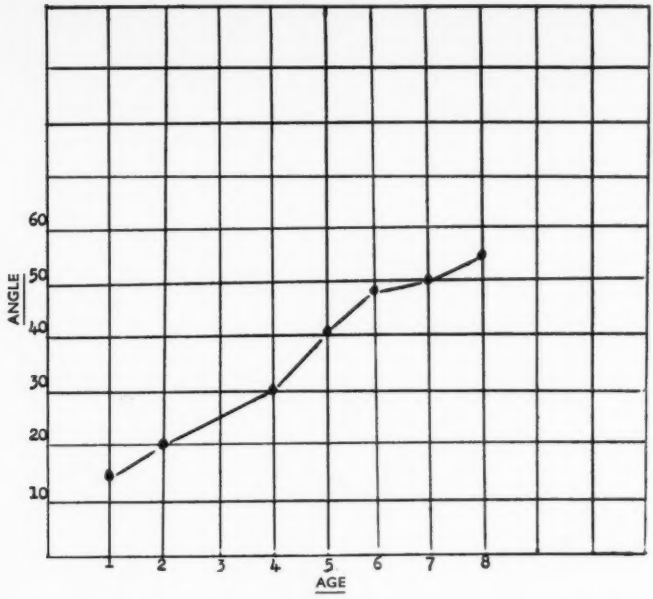

FIG. 1

Severe paralysis at seven months, with gross muscle imbalance of trunk and limbs. Curve increase from 15 degrees to 55 degrees in eight years. Apex of curve at T.7; convex to the left.

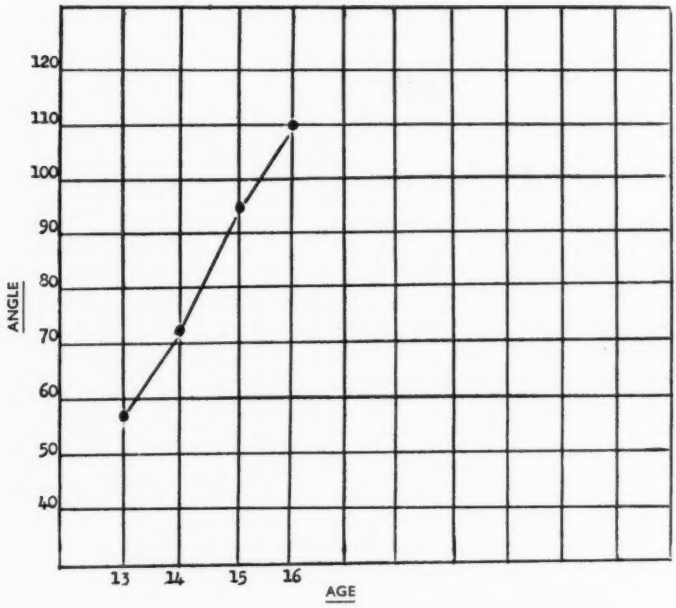

FIG. 2

Paralysis at age seven, with almost full recovery. Lateral curve first detected at age twelve. Curve increase from 56 degrees to 110 degrees in four years. Apex of curve at T.7; convex to the right.

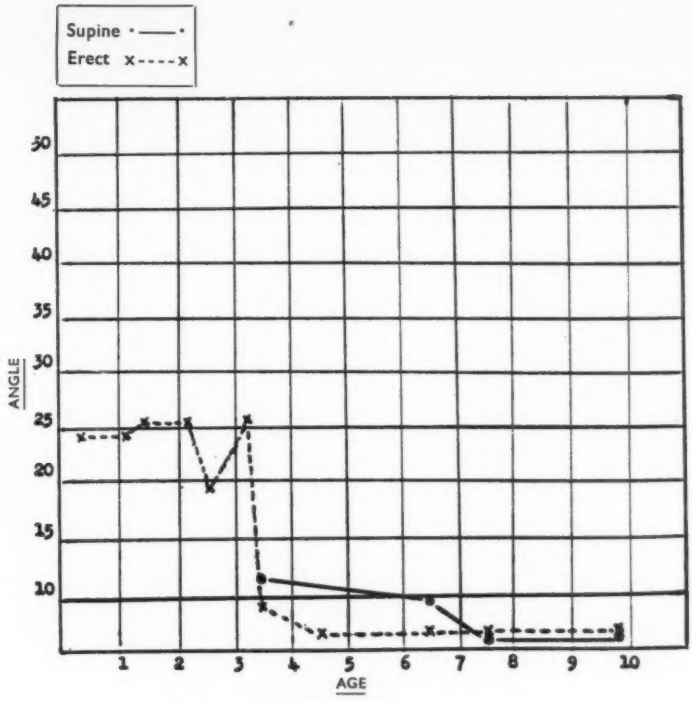

FIG. 3
Case 1—Chart showing the regression of the curve.

FIG. 4

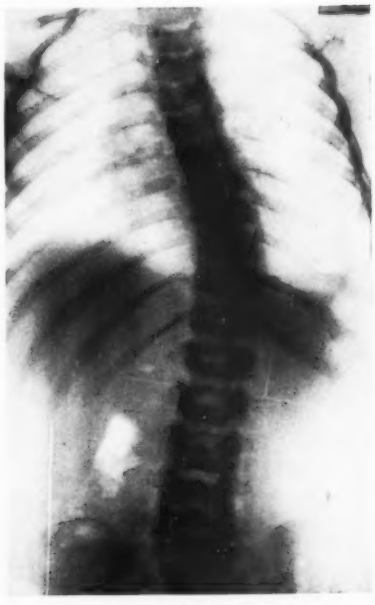

FIG. 5

Case 1. Figure 4—Initial radiograph, at age six months. Figure 5—At age two years.

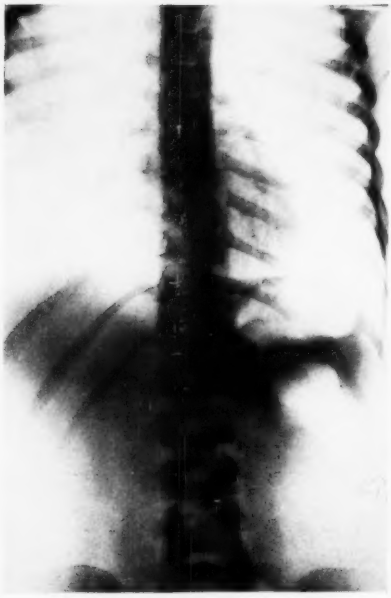

FIG. 6

FIG. 7

Case 1. Figure 6—Radiograph at age four and a half years. Figure 7—At age ten years.

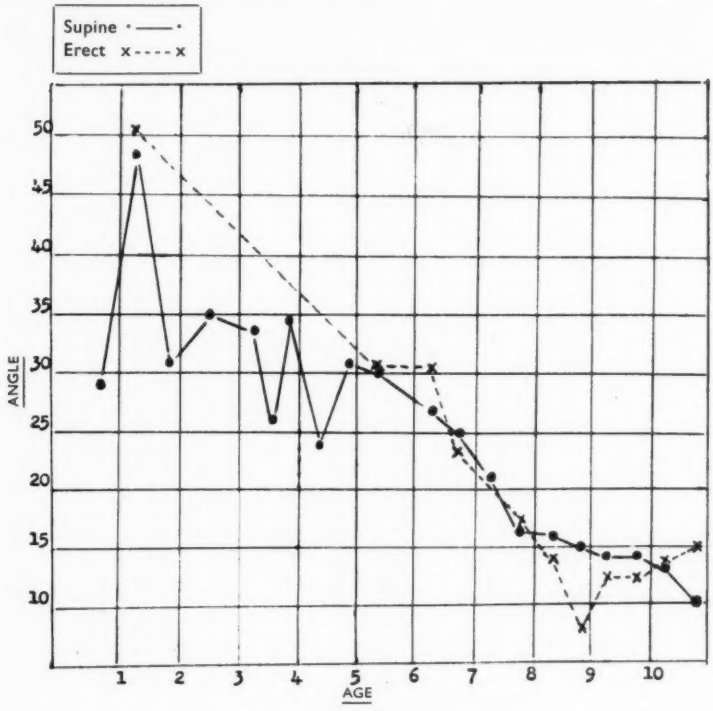

FIG. 8

Case 2—Chart showing the gradual regression of the curve.

FIG. 9

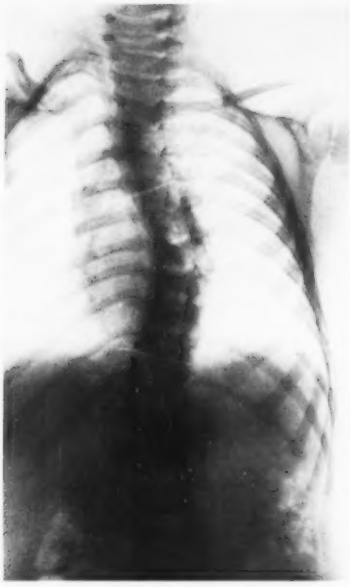

FIG. 10

Case 2. Figure 9—Radiograph at age two years. Figure 10—At age four years.

FIG. 11

FIG. 12

Case 2. Figure 11—At age six years. Figure 12—At age eleven years.

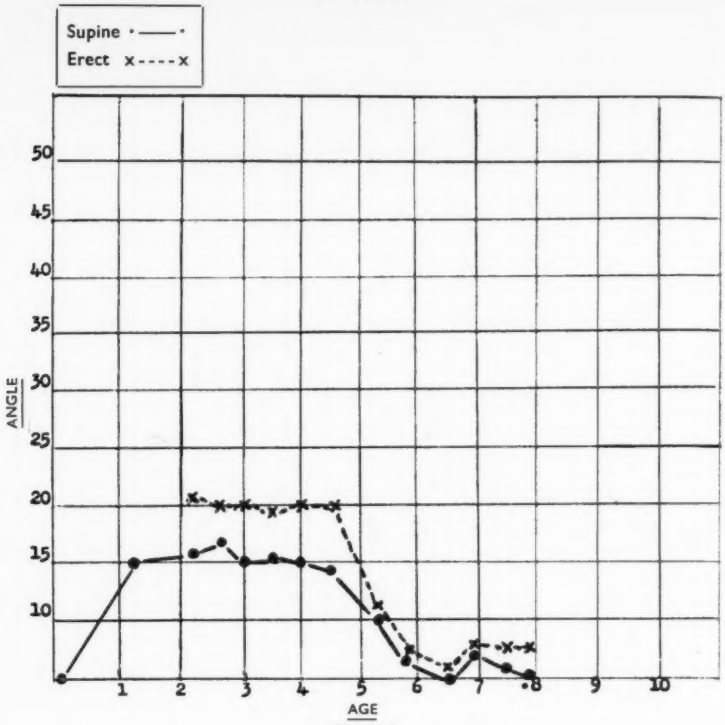

FIG. 13
Case 3—Chart showing regression of the curve.

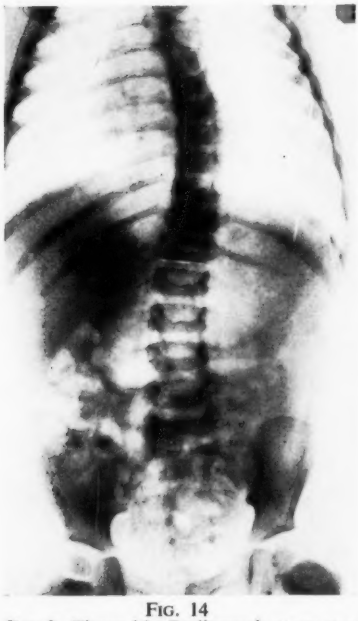

FIG. 14

FIG. 15

Case 3. Figure 14—Radiograph at age one and a half years. Figure 15—At age two and a half years.

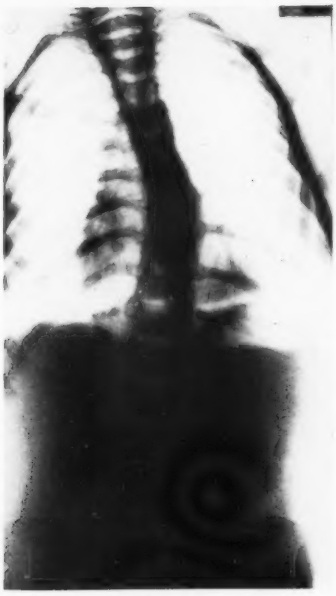

FIG. 16

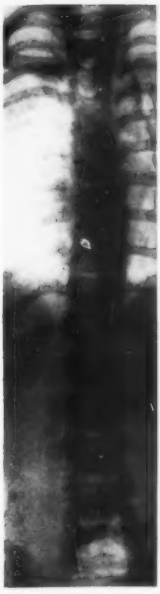

FIG. 17

Case 3. Figure 16—At age four years. Figure 17—At age eight years.

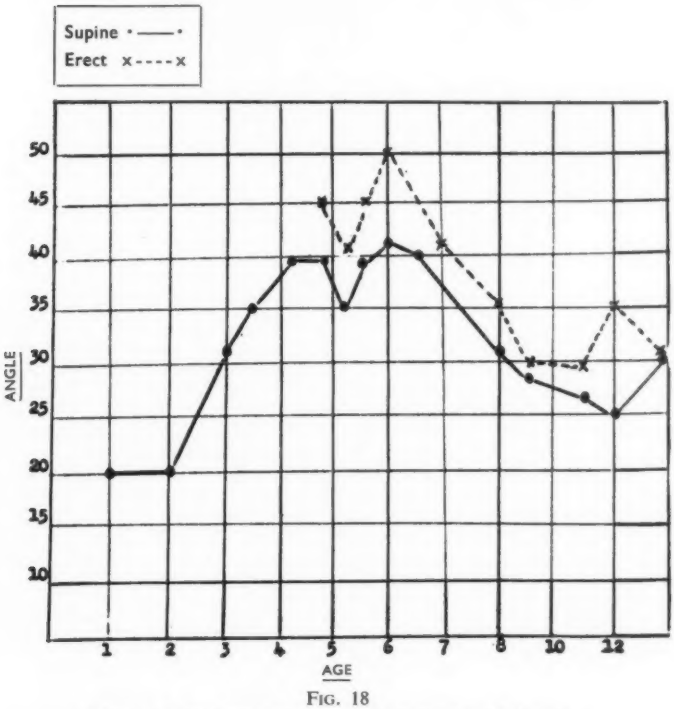

FIG. 18

Case 4—Chart showing progress and regression of the curve.

FIG. 19

FIG. 20

Case 4. Figure 19—Radiograph at age one year. Figure 20—At age three years.

FIG. 21

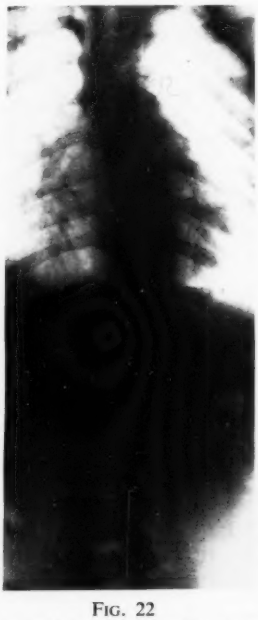

FIG. 22

FIG. 23

Case 4. Figure 21—At age four and a half years. Figure 22—At age ten years. Figure 23—At age thirteen years.

Case 4—Child born in December 1944. No abnormality in pregnancy or delivery. A lateral curve was recognised at ten months. It extended from T.6 to T.11 and was convex to the left. The child was otherwise normal, and reached a height of 5 feet at the age of thirteen. After increasing from 20 degrees to 42 degrees in the first six years of life the curve gradually decreased during the next six years (Figs. 18 to 23).

COMMENT

These cases are of particular interest in that they all fall into the infantile idiopathic group, and all might have been expected to proceed to severe deformity. They were recognised at a time when full spinal growth was ahead, and all had the type of structural changes so often seen in the early stages of the progressive curve. It is of interest that the curve pattern was the same in the four patients. The significance of this is slight in so small a number—many of the severe curves occupy this same area—but in the progressive type the apex tends to be higher and the curves shorter.

None of these patients had any treatment which could have affected the outcome in any way. Repeated radiography was the most active step taken in any of them.

These are challenging observations. There can be little doubt that they carry a message which should be of assistance in the solution of this baffling problem. Speculation as to what the corrective force is, and how it operates, is of little value at this stage, but reports of all the cases of this type may well add vital information.

SUMMARY

Four cases are reported in which infantile idiopathic structural scoliosis gradually decreased during the period of active growth.

I wish to thank all my colleagues at the Nuffield Orthopaedic Centre who have sent me their patients, and also Miss Craib, clinical photographer at the Centre.

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DISLOCATION OF THE UPPER END OF THE FIBULA

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Dislocation of the superior tibio-fibular joint is unusual. When it occurs it may escape recognition, and this may explain the scant attention that has been accorded to the condition in surgical literature. Even comprehensive text-books on joint injuries tend to dismiss this one in a few lines. It has been said that " the head of the fibula is like a poor relation of the knee." Complete dislocation apart, if this region be carefully examined whenever the tibia or the ankle has been damaged, it will be found that minor degrees of injury to the superior tibio-fibular joint are not uncommon.

Nélaton (1874) described the first recorded case, in a patient treated by Sanson, one of his colleagues. Since then little has been written about the injury: one comprehensive review was published by Lyle in 1925, and some cases were reported more recently in parachutists (Lord and Coutts 1944, Vitt 1948).

The purpose of this paper is to report five cases and to discuss the types of dislocation, the clinical features and the treatment.

CASE REPORTS

Case 1—A man aged thirty-four stepped from a stile on to his left leg. The ground was slippery, and his leg slid medially behind the right, and he sank down on it. He immediately complained of pain over the outer aspect of the knee. One of us (J. C. R. H.) was with him, and found the left fibular head dislocated forwards. Reduction was easily accomplished by pressure on the upper end of the bone, which caused a distinct click and immediate relief from the pain. The patient was able to walk forthwith, but had a vague discomfort in the leg for a few days.

FIG. 1

Case 2—Lateral radiographs showing the excursion of the head of the fibula.

Case 2—An Indian man aged twenty-seven was admitted to hospital for recurrent locking of his right knee, ascribed to a torn lateral cartilage after an injury four months before. It was noticed that the heads of both fibulae were abnormally prominent and mobile. They could be moved in a medio-lateral direction through about half an inch. Radiographs confirmed this excursion (Fig. 1). The patient stated that he had been conscious of this mobility since childhood, and as a schoolboy would

absent-mindedly push the fibula to and fro himself. Many of his other joints—notably in his fingers—were hypermobile. He played many games and, though he had twisted his right knee hard enough to tear the lateral cartilage, he had never experienced symptoms attributable to a dislocation.

Case 3—A woman aged forty-five fell from a window fifty feet above a stone pavement. She was admitted with multiple injuries which included a grossly displaced fractured pelvis, a comminuted fracture of the left femur, a crushed lumbar vertebra and an open fracture of the right great toe. During the three or four days after her admission attention was focused on these serious injuries and on her critical general condition. It was then noticed for the first time that the head of the right fibula was unduly prominent and tender (Fig. 2). Radiographs confirmed the existence of an anterior dislocation (Fig. 3).

This patient recovered from her fractures. The fibular dislocation remained unreduced, and the head of the bone was still tender six months later. She was eventually able to walk without any discomfort in the leg, but her gait has been affected by her other injuries.

FIG. 2
Case 3—The dislocated upper end of the right fibula has given rise to a swelling on the lateral aspect of the knee.

Case 4—A man aged thirty gave an exact description of the way in which he injured his leg. While he was walking across a sloping hillside his lower foot (the right) slipped, causing him to slide sideways. He fell with his right leg extended, and sat down heavily on his left leg, which was flexed beneath him.

He felt pain over the outer side of the left knee, and was able to bear weight only with discomfort. When he was seen in hospital later the same day the head of the fibula was palpable to the front and

FIG. 3
Case 3—Dislocation of the upper end of the fibula.

outer side of the lateral tuberosity of the tibia. Any attempt to move the fibular head caused severe pain, but movements of the knee were full and painless. Radiographs showed an anterior dislocation of the fibula (Fig. 4).

The first attempt to reduce the deformity after infiltrating the area with a local anaesthetic was unsuccessful. The next day a second attempt was made under general anaesthesia, but this also failed.

FIG. 4
Case 4—Dislocation of the upper end of the fibula.

Open reduction was performed a few hours later, through a curved longitudinal incision over the head of the fibula. Part of the extensor digitorum longus was stretched over the bone and was dissected off it. The joint capsule was incised anteriorly, and a metal spike was inserted under the fibular head and used to lever it laterally. The head then returned to its normal position with a snap, and appeared stable. A pressure dressing was applied. The patient was able to walk with only a slight limp four days later. Three weeks later the function of the leg was normal.

FIG. 5

Case 5—A man aged thirty-two was brought to hospital from a nearby playing field where he had injured his right knee during a game of rugby football. The injury was sustained when he was heavily tackled, but he could not describe the exact form of the strain thrown on his knee, or the direction in which it had acted. On attempting to stand, he had felt a severe pain in the knee and became conscious of a tender

FIG. 5
Case 5—Photograph showing the deformity of the right knee caused by dislocation of the upper end of the fibula.

FIG. 6
Case 5—Radiographs showing anterior dislocation of the fibula.

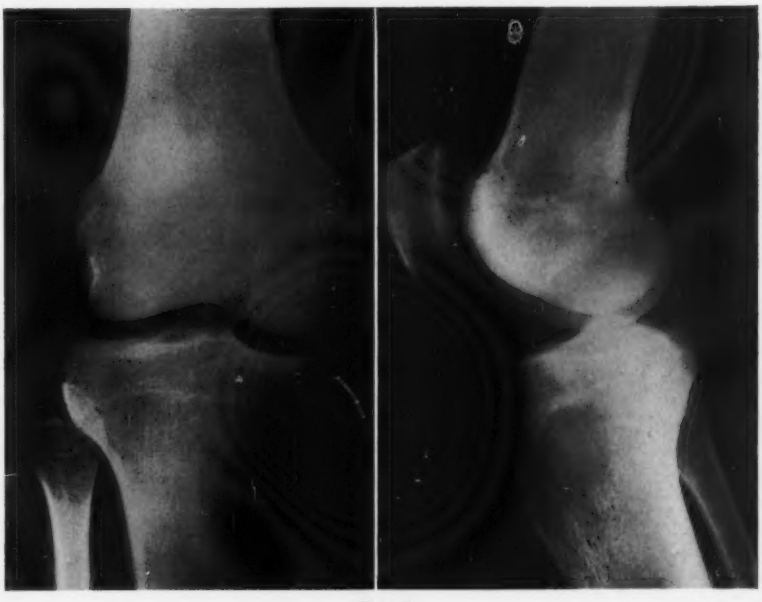

FIG. 7
Case 5—Normal radiographs of the same knee taken three years earlier, for comparison.

swelling at its lateral side. Three years earlier this knee had been injured in a similar fall. On that occasion, too, a painful swelling had appeared at the lateral side, but the patient had immediately manipulated the knee himself, whereupon the deformity disappeared and normal function was soon restored.

When seen an hour and a half after the injury the patient was unable to stand except with his knee slightly flexed. The displaced head of the fibula formed a prominent and tender swelling at the side of the knee (Fig. 5). There was no effusion, and full flexion of the joint was possible, but the last few degrees of extension caused discomfort. There was no neurological disturbance.

Radiographs confirmed the existence of an anterior dislocation of the fibula (Figs. 6 and 7). An attempt at reduction while the patient was conscious was abandoned on account of severe pain. Thirty minutes later the dislocation was easily reduced under general anaesthesia. A thumb was placed on the fibular head, and with the knee slightly flexed pressure downwards and backwards restored the bone to its normal position with a loud click. The reduction appeared stable. No dressing was applied and full function was regained within four days.

DISCUSSION

ANATOMY

The superior tibio-fibular joint is a plane articulation between two facets each invested with cartilage, and having a synovial lining which may communicate with the knee. Its size, shape and mobility are all subject to considerable variation; and it has been shown (Barnett and Napier 1952) that the plane in which it lies may vary from being almost horizontal to one steeply inclined to the horizontal. It may well be that the ease, or otherwise, with which dislocation occurs is related to the plane and mobility of the joint, but we have not been able to discover any report on this subject. Ordinary radiographs, such as those from our own patients, do not show the joint in sufficient detail to permit of any conclusion being reached.

The joint depends for stability on the structures distal to it which bind the tibia and fibula together—the interosseous ligament, the fibrous bands about the lower tibio-fibular joint—and on the ligaments of the superior joint itself. These consist of anterior and posterior thickenings in a tough capsule, the anterior being the more pronounced. They run to the front and back of the lateral condyle of the tibia, and there blend with the bone.

Of the structures related to the joint, the lateral popliteal nerve, which lies on the neck of the fibula, is the most noteworthy inasmuch as it sometimes suffers injury when dislocation occurs.

From the foregoing, and from a study of the skeleton, it will be realised that the head of the fibula, though normally firmly secured by the ligaments described, is in a potentially unstable position. If the ligaments are torn, it is liable to roll forwards or backwards on the circumference of the tibia; and these are, in fact, the displacements commonly observed.

Anterior dislocation—Previous writers (Lyle 1925, Peregalli 1955) are agreed that anterior dislocation is about twice as common as posterior dislocation, and it is to that group that our present series belongs. There is similar agreement on the usual mechanism by which the injury is produced—a fall with the knee flexed and adducted. A typical history is that related in our Case 1, and the patient in Case 4 suffered very similar violence. It seems certain that both these patients, in falling extended one leg before them. The rear leg adducted beneath it, and they sat down heavily on it. In such a position the biceps tendon, contracting violently, jerks the head of the fibula laterally, and produces a subluxation. (All anterior dislocations are initially lateral ones, for the plane of the joint is behind the lateral condyle of the tibia.)

Sometimes the injury is caused by falling from a height (see Case 3) and it is interesting that several dislocations have been described in parachutists.*

* A parachutist is trained to land with his feet together and his knees slightly flexed. He is blown across the ground by the prevailing wind and may well, if "coming in sideways," have one leg forced behind the other as he subsides on both.

For the sake of completeness mention should be made of the occasional occurrence of this injury simply from a violent muscular contraction. Thus Klose's patient, cited by Lyle (1925), dislocated his fibula as he sprang up from a kneeling position.

Posterior dislocation—Dislocation of the fibular head posteriorly is much more unusual. Descriptions of the condition in the literature suggest that it occurs about half as frequently as anterior dislocation. Its importance lies in its liability to be complicated by peroneal nerve lesions, which otherwise are rare. Backward dislocation is usually the result of direct violence to the knee in flexion when, the superior tibio-fibular ligaments having been torn through, the action of the biceps determines the position of the fibular head.

Upward dislocation—Unlike those previously described, this deformity—sometimes termed total dislocation—cannot occur as an isolated injury. It is, in any event, rare, but when it occurs it forms part of a serious ankle injury, usually sustained by a fall from a height. The foot is forced laterally, diastasis of the lower tibio-fibular joint occurs and the whole fibula—which may or may not fracture—is forced proximally until its upper end dislocates. The interosseous membrane of the leg must suffer coincidental damage, but the direction (downwards and laterally) of a majority of its fibres is such that they probably do not rupture.

Non-traumatic dislocations or subluxation—To the foregoing must be added a group of patients in whom the fibular head has become displaced in consequence of a local growth disturbance such as that induced by acute osteomyelitis. The lesion is sometimes seen in amputation stumps; or may occur as part of a congenital state associated with lax ligaments (Case 2).

CLINICAL FEATURES

Immediately after injury the patient may be unable to walk because of pain felt about the lateral side of the knee on weight bearing. Inspection reveals the fibular head lying in an abnormal position, where it is easily palpable between thumb and forefinger. The soft tissues about it—probably because they are relatively avascular—show little swelling or bruising. The head itself is extremely tender and the biceps tendon stands out in unnatural relief (unless, it is said, the displacement is upwards, relaxing the tendon). Hydrarthrosis and haemarthrosis of the knee are not seen in simple dislocations. Movements of the knee are not markedly restricted, but inversion and eversion of the ankle may be precluded by pain which is felt at the site of the dislocation. Neurological complications are rare, but should be sought. A foot drop is unusual, but on occasion there is some numbness of the foot for a few days after the injury.

These features are characteristic enough to permit an exact diagnosis, but in one of our patients (Case 3) the condition was not recognised because she was suffering from several other and more serious injuries.

TREATMENT

The dislocation can usually be reduced by a simple manipulation: the foot is strongly inverted, the knee is flexed to relax the beceps tendon, and, on the application of direct pressure to the head of the fibula, it returns to its normal position with an audible snap.

Once reduced, the dislocation will not usually recur. A crepe bandage, or strapping, is commonly advised and a few days' rest enjoined. The patient may thereafter bear weight on the injured limb and should receive physiotherapy to restore full function.

If manipulation does not effect a reduction, or if the dislocation recurs, operation is indicated. It has been suggested that open reduction is more often required in posterior dislocations than in anterior ones. Recourse to operation was necessary in one of our cases in which the shape of the lateral tuberosity of the tibia was considered to be responsible for the failure of manipulative treatment.

Other authors have reported instances of instability and recurrent dislocation after reduction. In such a case treatment might be either by arthrodesis of the joint or by temporary fixation with a transfixion pin or screw.

SUMMARY

1. Dislocation of the upper end of the fibula is probably less unusual than the paucity of the published reports suggests.
2. Dislocation may be anterior or posterior, anterior dislocation occurring about twice as often as posterior. Rarely the fibula moves proximally.
3. In most cases a closed manipulation suffices for reduction, and a full and rapid return of normal function follows.
4. Five cases are described. In one case operative reduction was required.

We acknowledge with gratitude the permission of Mr Charles Gray to report one of these cases, and the assistance we have received from the Photographic Department of the Royal Free Hospital in the preparation of the illustrations.

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SIMPLE DISLOCATION OF THE SUPERIOR TIBIO-FIBULAR JOINT

Report of a Case

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From the Bairnsdale District Hospital

Dislocation of the superior tibio-fibular joint has been reported only forty-six times. Macklin, Hartmann and Peterson (1940) reported forty cases of simple anterior or posterior dislocation. Vitt (1948) reported four cases, and Delaney, MacDonald and MacNab (1956) reported another two cases.

CASE REPORT

A footballer aged eighteen was one of four players leaping for the ball at the same time. He was bumped as he was coming down and landed with his extended foot and leg inverted under him. He was conscious only of an intolerable pain in the knee and was unable to bear weight.

On examination, the head of the fibula was immediately apparent in a forward position, and was exquisitely tender on palpation. He complained of " pins and needles " in the outer border of the calf, but there was no paresis. Radiographs showed the head of the fibula displaced anteriorly (Fig. 1).

Under thiopentone anaesthesia the dislocation was reduced easily by backward pressure of the thumbs with the knee extended (Fig. 2).

The knee was rested in a plaster cylinder from groin to ankle for two weeks. Since its removal he has displayed no disability.

FIG. 1
Radiographs showing the dislocation.

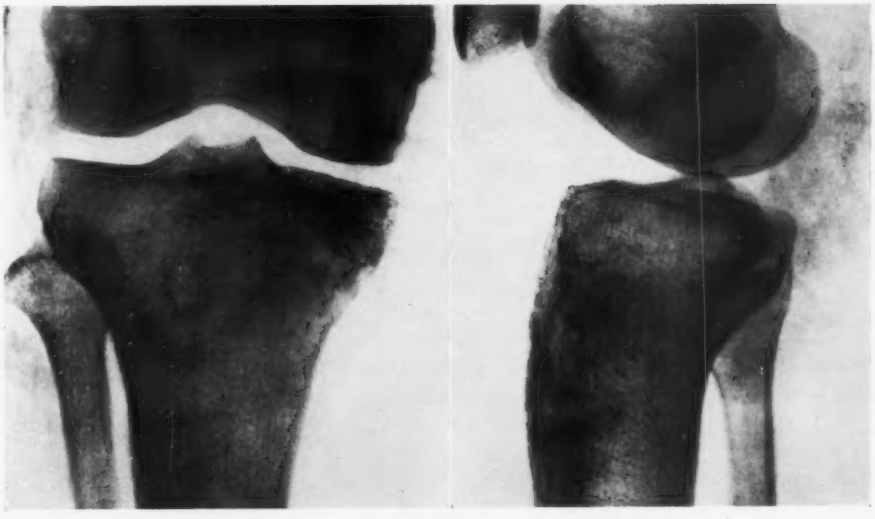

FIG. 2
Radiographs through plaster, after reduction of the dislocation.

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INTERNAL FIXATION IN THE TREATMENT OF FRACTURES OF THE SHAFTS OF THE RADIUS AND ULNA IN ADULTS

The Value of Delayed Operation in the Prevention of Non-union

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Formerly of the Birmingham Accident Hospital

Fractures of the shafts of the radius and ulna require more accurate reduction than do fractures of the shafts of other long bones, because malunion in these injuries may result in serious loss of pronation and supination. Although some of these fractures can be treated conservatively, others are encountered in which closed treatment fails and open reduction and internal fixation are required.

LIMITATIONS OF CONSERVATIVE TREATMENT

A good reduction may not be obtained or may be lost when the initial swelling subsides. Union of these fractures is often slow and a period of four or five months in plaster is often necessary. There is with conservative, as with operative, treatment a definite incidence of non-union, which with conservative treatment is about 6 per cent. When union is slow a gradual deterioration in position can occur over a period of weeks or months, sometimes necessitating a late operation which can be difficult and unsatisfactory. Despite these limitations, conservative treatment is the method of choice for patients in whom reduction can be obtained and maintained.

It is undesirable to compare the results of conservative with those of operative treatment because the latter should generally be used only for fractures not suitable for conservative measures, or when those measures have failed. Precise indications for operation cannot easily be laid down and may be misleading. The surgeon who is not prepared to make full use of both methods cannot give of his best in the treatment of these difficult fractures.

The principles of conservative treatment were well described by Evans in 1951. This paper will in some ways be complementary to that report because it describes the experience gained in a series of forearm fractures treated by internal fixation.

MATERIAL

The present review covers seven years from 1950 to 1956, during which 112 adults with fractures of the shafts of the radius and ulna were treated by open reduction and internal fixation. The term " adult " is used to include those in whom the epiphyses had either fused or were about to fuse; a few children who required internal fixation are excluded from this

TABLE I

THE CAUSE OF 130 FRACTURES TREATED BY OPERATION IN 102 PATIENTS

Traffic accidents 46	Falls 37	Industrial accidents 19

study. In ten patients who could not be traced there was insufficient information for assessment, leaving 102 patients with a total of 130 fractures treated by internal fixation. Fractures very close to the joints—that is, the uppermost and lowermost fifths of the bones—are also excluded from this review. All patients were kept under observation for at least a year. In assessing the time required to obtain union, only radiological evidence was used because clinical

impressions are sometimes misleading. Most of the patients had been radiographed at approximately monthly intervals until union was obtained, and this made accurate assessment of the time to union relatively easy.

The 112 patients represent the collective material of six surgeons working in busy fracture units. In seven years, therefore, each surgeon on the average encountered less than twenty patients requiring internal fixation for these fractures—about three patients a year. Normally extensive personal experience is, therefore, not gained rapidly.

The causative violence is shown in Table I. Whereas traffic accidents and falls caused the largest number of injuries, some of the most severe were from accidents with industrial or agricultural machinery. There were seventy men and thirty-two women.

The patients' ages are shown in Figure 1. The large number of fractures occurring between the ages of twenty and twenty-nine is due to the frequency of motor cycle accidents.

Seventeen of the injuries were compound, eight with serious wounds and severe soft-tissue damage, and nine with puncture wounds.

The anatomical varieties of fracture are shown in Table II. Most of those requiring operation were fractures at the junction of the middle and lowermost thirds of the radius with inferior radio-ulnar subluxation or dislocation.

TABLE II

ANATOMICAL VARIETIES OF INJURY

Fractures of the radius with inferior radio-ulnar subluxation or dislocation	39
Fractures of the middle thirds of the radius and ulna	28
Fractures of the junction of the middle and lowermost thirds of the radius and ulna	22
Fractures of the lowermost third of the radius and neck of the ulna	5
Fractures of the ulna with dislocation of the head of the radius (Monteggia fracture-dislocation)	2
Double fractures of the radius and ulna	2
Fractures of the uppermost thirds of the radius and ulna	1
Displaced fractures of the lowermost third of the ulna	3
Total patients	102*

* Four of these patients had associated fractures of the shaft of the humerus and two patients had dislocations of the elbow in addition to the two patients with the Monteggia fractures.

METHOD OF INTERNAL FIXATION

The most satisfactory fixation was that obtained from well applied metal plates and screws. Experience with medullary nailing has been small and not very favourable. The nail is sometimes difficult to insert in the radius because of the curve of the bone, and it seldom prevents rotatory movement of the fractured ends. The method is sometimes of value in the treatment of certain severe compound injuries with skin loss.

Cerclage wires, Kirschner wires and other precarious methods of fixation are not usually satisfactory and are sometimes harmful.

Primary autogenous bone grafting was done in a few patients. The use of large tibial grafts greatly increases the extent of the operation, and is not justifiable as a primary measure. Union is not necessarily more rapid than after accurate plating.

In fractures in which there is displacement and overlap of both bones, it is usually advisable to plate both radius and ulna.

RESULTS AND COMPLICATIONS

The results were good or satisfactory in seventy-four of the 102 patients, and unsatisfactory in twenty-eight for the following reasons:

Non-union	17
Slow union with resulting deformity	5
Untreated deformity of ulna	4
Serious wound infection	1
" Partial " cross union	1

The only serious wound infection occurred in a patient operated upon for the second time, when a Küntscher nail was inserted with some difficulty into the radius. A discharging sinus persisted for several months but eventually healed. The fracture united despite the infection, the nail being left in place till union occurred.

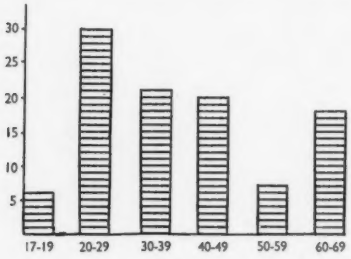


FIG. 1

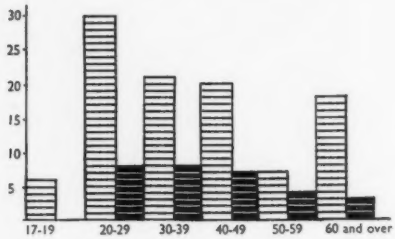


FIG. 2

Figure 1—Age in years of the patients in this series. Figure 2—Age in years of patients with non-union and slow union.

Something approaching a cross union occurred in one case only. The bones were plated as usual through separate incisions. Fortunately a pseudarthrosis developed in the strut of bone between the radius and ulna which allowed some rotation. The patient was pleased with the result, and happily so were some others whose operations have been listed as failures.

Less serious complications, not contributing to the list of failures, were:

Slow union without resulting deformity	8
Transient posterior interosseous nerve palsy	2
Troublesome anaesthesia from division of cutaneous branch of radial nerve	1
Minor wound infections	2
Mild ischaemic contracture with recovery	1

Non-union—Of twenty-eight unsatisfactory results, twenty-two were due to non-union or slow union and these clearly are the main hazards in treatment by internal fixation. For this reason the subject of non-union was given special study.

In this series *slow union* was said to be present if advanced radiological union was not present six months after injury; *non-union* if a year had elapsed without union or if bone grafting or some other operation for non-union had been carried out.

The rate of non-union of these fractures in adults treated conservatively is about 6 per cent. The rate of non-union in reported collective series treated operatively varies between 9 and 30 per cent; the figure in this series is nearly 17 per cent.

In the causation of non-union these factors were found to be of importance: 1) the severity of the injury and the extent of soft-tissue damage; 2) the site of fracture; 3) the age of the patient; 4) the quality of internal fixation; 5) plaster fixation after operation; and 6) the timing of the operation.

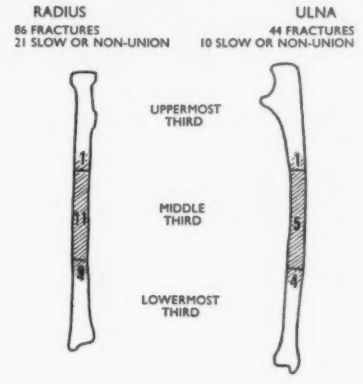
Severity of injury—As might be expected, union was in general slower after the more severe injuries. Of the seventeen compound fractures, some of which were very severe, six went on to non-union or required bone grafting.

Site of fracture—Non-union was commonest in fractures of the mid-shaft and in fractures at the junction of middle and lowermost thirds, but this partly reflects the increased frequency of injury at these levels. There was no substantial difference in the incidence of non-union in the radius as compared with the ulna. The sites of thirty-one fractures with slow union or non-union are shown in Table III.

TABLE III

SITES OF THIRTY-ONE FRACTURES WITH SLOW OR NON-UNION

Site of fracture	Radius	Ulna
Junction of middle and uppermost third	1	1
Middle third	11	5
Junction of middle and lowermost third	9	4
Total fractures with slow or non-union	21	10
(Total of fractures in the series)	(86)	(44)



Age—Delayed union and non-union were most frequent in patients between the ages of thirty and fifty-five—the intermediate age group. It was lower in those under thirty and in those over sixty, as shown in Figure 2.

Quality of internal fixation—The quality of internal fixation was important. Several fractures developed non-union because the plate was very small or poorly applied; rigidity of internal fixation, however, bore no relation to speed of union. Union with poor fixation was often rapid, and that with good fixation often slow. Nevertheless a well applied plate can often hold a fracture for a long time in relative safety, and poor internal fixation should be avoided. Medullary nails are less satisfactory than plates. Firm fixation, though desirable, cannot always be achieved, because of comminution or proximity of the fracture to the bone end.

Plaster fixation—Some difference of opinion exists about the use of plaster after internal fixation. The results in the present series suggest that non-union is more common in fractures not treated in adequate plasters.

Ninety-three fractures had been immobilised in plaster for adequate periods, of which nine developed non-union. Of thirty-seven fractures which had either no plaster at all or plaster for short or irregular periods eight developed non-union.

While the speed of functional recovery in cases successfully treated without plaster is very striking, the higher incidence of non-union makes routine use of the method unjustifiable.

The timing of operation—Since the paper by Murray in 1941 on " The timing of the fracture-healing process" it has been widely believed that the best time to carry out internal fixation of a fracture is as soon after injury as possible. Immediate operation was believed to cause the least interference with the normal healing process. Added advantages of early operation are ease of exposure, ease of reduction and precise identification of damaged tissues unaltered by oedema and fibrosis. Most of the fractures in this series were subjected to early internal fixation.

In about a third of the total number, delayed operation was carried out for one or more of the following reasons: 1) Loss of reduction after manipulation or failure to obtain reduction after repeated manipulation. 2) Patients transferred late from other hospitals. 3) Compound fractures in which operation was delayed to obtain skin healing. 4) Patients with severe associated injuries in whom treatment of the fractured forearm had to be delayed.

FIG. 3

A patient aged twenty-seven with a fracture of the radius and ulna which shows displacement, shortening and comminution.

Fractures of the shaft of the radius and ulna in adults do not ordinarily heal with abundant callus, but it was seen that in a few fractures the rate of healing was unusually brisk, with profuse subperiosteal callus. Further investigation showed that this was usually seen in patients who had a delayed operation and was seldom seen in fractures plated in the first six days. It was then decided to review the whole series with special regard to the timing of operation, and the results in our own cases were surprising; it was found that every fracture with non-union and most of those with slow union occurred in patients operated upon early, and in this series non-union did not occur in any patient operated upon after the sixth day. It should not be thought that all fractures treated by delayed operation showed union with abundant subperiosteal callus, for some showed no external callus at all; yet evidence of the benefits from delayed operation was strikingly shown in the final analysis when it was found that all the fifty-two fractures so treated united, fifty of them within six months of injury.

A detailed comparative analysis of patients treated by early and by delayed operation is shown in Tables IV to VIII, where it will be seen that there is no essential difference in the two groups as regards expectation of union at the time of injury.

TABLE IV

THE EFFECT OF EARLY AND DELAYED OPERATION ON COMPOUND FRACTURES OF THE FOREARM

Type of fracture	Early operation	Delayed operation
Severe, with extensive soft-tissue damage	6 fractures	2 fractures
	4 non-unions	No non-unions
Not severe, without extensive soft-tissue damage	6 fractures	3 fractures
	2 non-unions	No non-unions

To summarise the contents of the Tables, the adverse factors in the expectation of union are: 1) compound injuries; 2) fractures of middle and lowermost thirds of the bones; 3) age between thirty-five and fifty-five, at which age patients seem most prone to non-union; and 4) severe soft-tissue damage.

TABLE V

AGES OF 102 PATIENTS WITH FRACTURES OF THE FOREARM TREATED BY EARLY AND DELAYED OPERATION

Age (*years*)	Early operation (*patients*)	Delayed operation (*patients*)
17–19	2	4
20–29	21	9
30–39	14	7
40–49	11	9
50–59	4	3
60–69	11	7
Total patients	63	39
(Total fractures)	(78)	(52)

TABLE VI

ANATOMICAL VARIETIES OF FRACTURES TREATED BY EARLY AND DELAYED OPERATION

Type of injury and site of fracture	Early fixation (*patients*)	Delayed fixation (*patients*)
Middle thirds of the radius and ulna	14	14
Lowermost third of the radius and ulna	11	11
Lowermost third of the ulna	2	1
Lowermost third of the radius with inferior radio-ulnar subluxation	12	7
Lowermost third of the radius with inferior radio-ulnar dislocation	7	2
Middle third of the radius with inferior radio-ulnar subluxation	8	3
Shaft of the ulna with dislocation head of radius	2	—
Double fractures of the radius and ulna	2	—
Lowermost third of the radius and neck of the ulna	4	1
Uppermost third of the radius and ulna	1	—
Total patients	63	39

TABLE VII

COMPARISON OF THE TYPES OF INJURY TREATED BY EARLY AND DELAYED OPERATION

Cause of fractures	Early operation (*patients*)	Delayed operation (*patients*)
Traffic accidents	27	19
Falls	24	13
Machinery accidents	12	7
Total patients	63	39

It will be seen that all these adverse conditions are well represented proportionately in the series treated by delayed operation. Also it should be mentioned that both series had been operated upon by the same group of surgeons.

FIG. 4

FIG. 5

Figure 4—Twenty-four days after the injury shown in Figure 3 the bone ends have been drilled at operation and the radius has been plated. Figure 5—Ten weeks after the operation union has occurred. The patient regained full function of the forearm.

THE TREATMENT OF NON-UNION

A hasty decision must not be made to reoperate on a fracture thought to have non-union, as many of these will eventually unite, however slow the initial progress has been. At the end of the third month it is common to see in the radiograph a gap between the fractured bone ends, as though the fracture had been plated in distraction; this gap is often obliterated in the next few weeks. Unless the plate and screws are very loose they should not be removed in the erroneous belief that they are holding the bone ends apart; to do this is often to invite non-union. In fractures where union is very slow, well applied plates may hold them securely for several months until union occurs. Multiple operations must be avoided as the tendency to non-union is thereby increased.

TABLE VIII

SUMMARY OF RESULTS OF EARLY AND DELAYED OPERATION

Type of treatment	United within 6 months	United within 12 months	Non-unions and bone grafts	Total
Early operation (first to sixth day).	49	12	17	78 fractures
Delayed operation (seventh day onwards)	50	2	—	52 fractures

If a plate needs to be removed before radiological union is complete, bone grafting is advisable. The appearances at operation are deceptive, and bony union may be thought to be present when no more than fibrous union exists, and the removal of the plate may be followed by non-union.

FIG. 6

FIG. 7

Figure 6—A patient aged thirty-seven with a fracture of the radius and inferior radio-ulnar subluxation has had internal fixation performed nineteen days after the injury. Figure 7—A radiograph of the same patient thirteen weeks after the injury shows advanced union of the radius with profuse subperiosteal callus often seen after delayed operation.

When bone grafting is undertaken, a large cortical graft should be used and fixed securely to the fractured bone ends. The results of this operation in the forearm are often unsatisfactory if good fixation is not obtained. Iliac bone should be avoided as this graft is inferior to that obtained from the tibia.

TABLE IX

RESULTS OF OPERATIONS FOR NON-UNION

	Operations	Failures
Large tibial bone graft . .	3	No failures
Small tibial bone graft . .	3	2 failures
Iliac bone graft + plate . .	2	1 failure
Sliding bone graft . . .	2	2 failures
Removal of plate and insertion of Küntscher nail . . .	2	1 severe wound infection
Iliac bone grafts . . .	6	3 failures

It is unwise to excise the lower end of the ulna to promote union in the radius because this frequently causes the radius to angulate towards the ulna and increases the difficulty in obtaining union.

DISCUSSION

The most serious complication of internal fixation in the present series has been non-union. With correct timing of the operation it should be possible to reduce this to negligible proportions;

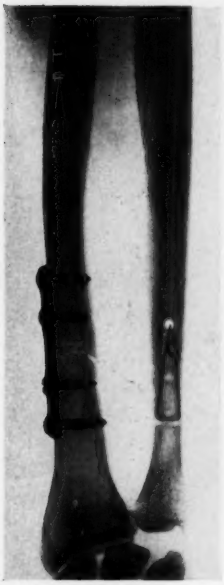


FIG. 8

FIG. 9

FIGS. 8 AND 9

Figure 8—Internal fixation done seven days after injury in a patient aged nineteen for a fracture of the lowermost thirds of the radius and ulna with displacement and shortening. Figure 9—A radiograph of the same patient shown in Figure 8 ten weeks after the injury shows massive callus formation and cross union. This was the only patient in whom cross union occurred in the series treated by delayed operation. Later a pseudarthrosis formed in the bridge and a limited but useful range of rotation was obtained.

even so, the writer believes that there is a definite place for conservative treatment in these fractures and if reduction can be obtained and maintained without internal fixation this is the treatment of choice.

FIG. 10

Twelve weeks before this radiograph of a patient aged seventy was taken the fracture of the radius with inferior radio-ulnar subluxation was plated. There is now union with abundant subperiosteal cartilage.

FIG. 10

Does deliberate delay greatly increase the difficulty of open reduction? In the case of the forearm it does not; a delay of seven days adds no difficulty at all, and even after a further two or three weeks the repair tissue surrounding the bone ends is still soft and easily peeled away

from the fracture site. This repair tissue should be handled gently and never excised, because it contributes to the healing of the fracture.

The blood supply to the soft tissues surrounding these fractures is often severely damaged, and early operation does further harm to the local circulation; delay presents the advantage of allowing the local circulation to re-establish itself, with improved prospect of bone union.

In wound healing in general the cellular response appears to reach its maximum between ten and twenty days after injury, as does an open granulating surface. The timing of operation when the local cellular response is fully developed is often followed by rapid healing, as in wounds treated by secondary suture. It seems that a similar favourable repair is obtained by delayed internal fixation in the treatment of fractures.

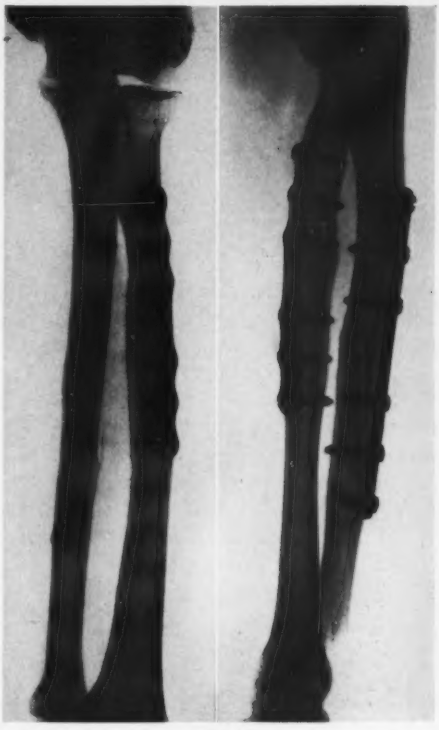


FIG. 11

Fractures of the radius and ulna with displacement and overlap in this patient aged twenty-three were plated three weeks after injury without undue difficulty. Union occurred in five to six months by gradual obliteration of the fracture line and with minimal subperiosteal callus. This less dramatic result is often seen after delayed internal fixation.

SUMMARY

The place of internal fixation in the treatment of fractures of the shafts of the radius and ulna in adults is discussed, and the results in 130 fractures treated by internal fixation are reviewed.

Non-union was found to be the most frequent and serious complication after internal fixation.

The incidence of non-union can be greatly reduced if operation is delayed for at least one week, and preferably two to three weeks after injury.

Evidence is presented to support the value of delayed operation in the promotion of union of fractures.

My special thanks are due to Mr William Gissane and Mr Denys Wainwright, who have read through the paper and offered much valuable advice and helpful criticism.

I would also like to thank the surgeons of the Birmingham Accident Hospital for allowing me to review patients under their care.

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OSTEOID OSTEOMA OF VERTEBRAE

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Osteoid osteoma is no longer a rare lesion. The two cases reported here did however present in an unusual fashion and did pose difficult diagnostic problems.

CASE REPORTS

Case 1—An eight-year-old boy was first seen by the senior author in November 1949, after poliomyelitis in July of that year. His upper and lower extremities and abdominal musculature were normal, but he stood with a decided cervical scoliosis, convex to the right. He complained of intermittent pain in the back of the left shoulder, occasionally radiating down the back of the left arm to the wrist, but not into the hand. The pain was present only at night. A radiograph of the left shoulder did not show any abnormality. During the next five months there was a gradual increase in the curve, and the pain in the shoulder increased. Spot radiographs of the upper thoracic and lower cervical regions revealed an area of increased density in the first thoracic vertebra, and osteoid osteoma was suspected (Fig. 1). A plaster jacket was applied for about a month without relief of the pain.

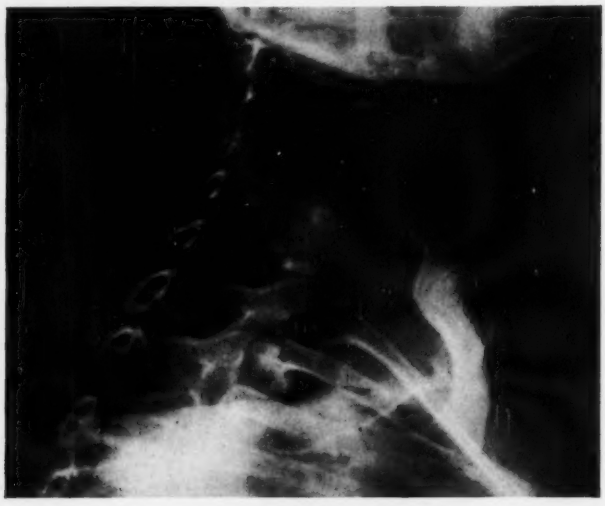

FIG. 1
Case 1—The zone of increased density in T.1 vertebra.

On his admission to the Hospital for Sick Children (Toronto), a three-foot standing film of the spine revealed that the angle of the primary curve had increased from 12 to 22 degrees (Fig. 2). A point of tenderness was present just above and medial to the superior angle of the left scapula, and pain was elicited there by applying pressure to the top of the head and forcing it to the left. However, the radiating pain could not be reproduced. Neither sensory nor reflex change was noted in the arm, but there was marked supraclavicular and infraclavicular wasting on the left. The sedimentation rate was 18 millimetres in the first hour

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FIG. 2

FIG. 3

Case 1. Figure 2—Three-foot standing radiograph of the spine with marked scoliosis convex to the right in upper thoracic and cervical regions. Figure 3—Three-foot standing radiograph of the spine six years after removal of the lesion.

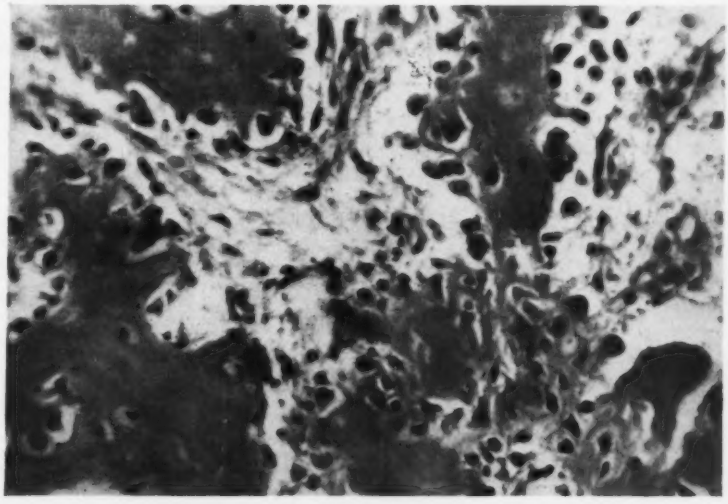

FIG. 4

Case 1—Photomicrograph of a section of the specimen. (×200.)

(Wintrobe), the white cell count 10,500 per cubic millimetre and haemoglobin 13·2 grammes per cent.

Operation—In April 1950 the lamina on the left of T.1 vertebra was exposed. This was curetted, and a discrete calcified nidus was found and removed (Fig. 4). The surrounding sclerotic process involved neural arch, body and articular process. Because of the destruction incident to removal of the nidus, an autogenous tibial bone graft was placed from C.7 to T.2 on the right side.

Progress—The boy was last seen in March 1956, six and a half years later. He still complained of occasional pain in the back of the left arm, but this was believed to be a sequela of the operation. Certainly the local tenderness, wasting and the night pain were no longer present, and a three-foot standing radiograph of the spinal column showed that the scoliosis had completely disappeared (Fig. 3).

Case 2—A ten-year-old boy was admitted to the Hospital for Sick Children (Toronto) in August 1950, with intermittent lumbar pain of six months' duration which was present on his arising in the morning and lasted for two or three hours each day. There was no complaint of pain at night. The pain was increased by forward flexion of the body, but not aggravated by exercise. There were no previous illnesses.

Examination revealed a healthy, well nourished boy. The head and neck, chest, abdomen and extremities were normal. The back showed marked spasm of the semispinalis muscle on the right in the lumbar region, with moderate scoliosis convex to the left extending from T.9 to L.4. There was reduced lateral flexion to the left and the normal lumbar curve had disappeared (Fig. 6). Spot films showed a circumscribed area of decreased density 1·5 centimetres in diameter in the first lumbar vertebral body, at the junction of the right neural arch and inferior articular process (Fig. 5).

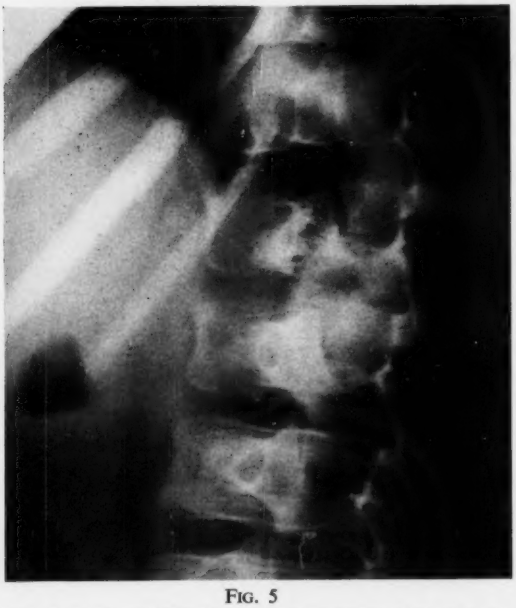

FIG. 5

Case 2—Spot radiographs of lumbar region with area of decreased density in region of articular facet of L.1.

Operation—The lesion in the lamina of L.1 was exposed by retracting the muscle mass on the right. A small piece of the muscle adjacent to the lesion was excised and submitted for frozen section. This was shown to be normal muscle with some fatty degeneration. The tumour was curetted, and was found to invade the articular facet, body and lamina. These and the spinous process were removed (Fig. 8). Bone flakes were turned down on the spinous processes of T.12 and L.2 vertebrae and an autogenous tibial bone graft was applied on the right side. The spinous processes of T.12 and L.2 vertebrae were wired together. A short body jacket was retained for three months.

Progress—Seen in March 1956 the patient had no complaint of back pain; clinically the back was straight and a three-foot standing film of the spine showed no curve (Fig. 7).

Histological examination—The specimens in both cases have been examined by Dr W. L. Donohue, of the Hospital for Sick Children (Toronto), who confirmed the diagnosis of osteoid osteoma (Figs. 4 and 8).

FIG. 6

FIG. 7

Case 2. Figure 6—Three-foot standing radiograph of the spine with scoliosis convex to the left. Figure 7—Three-foot standing film six years after operation.

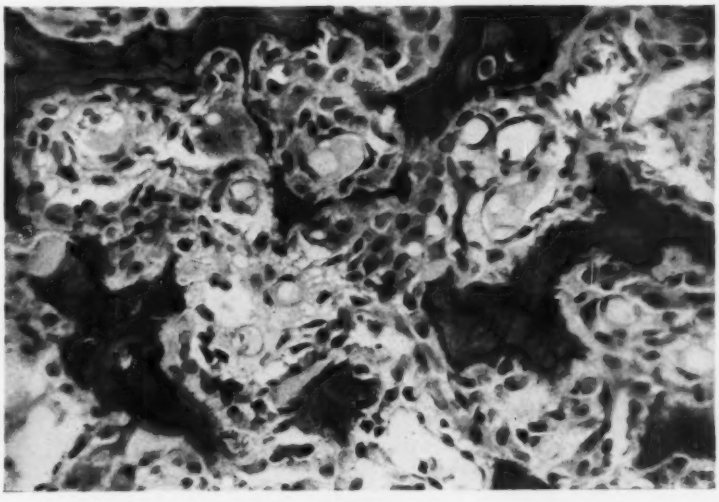

FIG. 8

Case 2—Photomicrograph of a section of the specimen. (×200.)

DISCUSSION

Both cases presented similar difficult diagnostic problems: 1) the appearance of a scoliosis, one apparently an idiopathic curve, and the other probably paralytic in view of the recent history of poliomyelitis and the apparent progression of the curve over a period of five months; 2) the definite and marked history of pain; 3) the gradual increase in severity of symptoms during six months; 4) the difficult radiological identification of the lesion in the vertebra; 5) the similar position of both lesions, each involving vertebral body, neural arch and articular facet; 6) relief of symptoms by curettage and removal of the lesion; and 7) disappearance of the scoliotic curve after removal of the lesion.

Of more than 280 cases of osteoid osteoma described since 1935 (Jaffe), only twenty-five have been in a vertebra (Fagerberg and Rudström 1953, Dahlin and Johnson 1954). Sherman (1947) alone has written of scoliosis as a presenting sign, although without detail.

Dahlin and Johnson (1954), describing four cases involving a vertebra, did not refer to scoliosis although a reproduction of a radiograph did show a mild scoliosis in one patient. Two of the lesions involved body, lateral mass and a facet, as in our two cases. Few detailed reports are to be found. Osteoid osteoma has been identified in the spinous process, and Dockerty, Ghormley and Jackson (1951) described one in the pedicle of the third lumbar vertebra.

There has been much speculation about the natural history of the disease. Sherman (1947*a*) discussed a case of Dr D. B. Phemister. An eighteen-year-old boy, seen before the publication of Jaffe's original description, had refused operation for a tibial lesion that radiologically would now be considered an osteoid osteoma. He returned twenty-four years later with a history of spontaneous remission of pain seven years after the onset, and a radiograph now showed no evidence of a nidus although the typical sclerotic bone persisted. Dockerty *et al.* (1951) described a seven-year-old girl with the clinical and radiological features of an osteoid osteoma of the femur. Her symptoms regressed in two years, and seven years later the radiograph appeared normal. Moberg (1951), considering the natural course of osteoid osteoma, illustrated his thesis of spontaneous regression by a metacarpal lesion that ceased to cause symptoms after two years. Additional indirect evidence for spontaneous remission of the lesion is that it seldom occurs in persons over thirty years of age.

After Jaffe had persuaded most writers that osteoid osteoma was a true tumour in spite of its self-limitation, three further cases have been reported that appear to revive the inflammatory theory. They were all adjacent to joints—two in the femoral neck, and one in the humerus in the synovium. The picture was identical, both grossly and microscopically, with that of rheumatoid arthritis (Sherman 1947*b*, Massachusetts 1955).

SUMMARY

1. Two cases of osteoid osteoma of the vertebrae are presented.
2. The unusual clinical histories and findings are reported in detail.

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A COMPARATIVE RADIOLOGICAL STUDY OF REITER'S DISEASE, RHEUMATOID ARTHRITIS AND ANKYLOSING SPONDYLITIS

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In a previous communication (Mason, Murray, Oates and Young 1958) we have described three groups of patients studied at the London Hospital in whom a diagnosis of Reiter's disease, rheumatoid arthritis and ankylosing spondylitis had been made. Reasons were given for regarding these as distinct entities and attention was drawn to the differences found in age distribution, in the incidence of inflammatory genital disease, in serology and in involvement of the sacro-iliac joints. The clinical features of the patients with Reiter's disease have been described by King (1957) and by Oates (1957); the radiological features were reported by Murray, Oates and Young (1958), who pointed out their similarity to those found in rheumatoid arthritis and ankylosing spondylitis. Previous accounts of the radiological appearances in Reiter's disease have usually been limited to isolated findings. Most workers have commented on the periostitis (Hollander, Fogarty, Abrams and Kydd 1945; Harkness 1950; Guck and Wolf 1952; Sharp 1957), especially that affecting the calcaneum (Ford 1953). Others have emphasised osteoporosis (Twiss and Douglas 1946, Corner 1950); however, Paronen (1948) found no radiological changes in 334 patients with post-dysenteric Reiter's disease and in 1955 Buchan stated that the radiological changes are " non-specific." Marche (1950), Ford (1953), Sharp (1957), Thompson (1957) and Mason *et al.* (1958) have all been impressed with the high incidence of " sacro-iliitis."

TABLE I

AGE DISTRIBUTION OF THE PATIENTS STUDIED

Age in years	15–24		25–34		35–44		45–54		55–64		65–74		75 onwards	
	Number	Per cent	Number	Per cent	Number	Per cent	Number	Per cent	Number	Per cent	Number	Per cent	Number	Per cent
Reiter's disease	3	12	4	16	6	24	6	24	2	8	3	12	1	4
Rheumatoid arthritis			5	6	14	17	28	35	23	28	11	14		
Ankylosing spondylitis	8	21	6	16	16	42	6	16	2	5				

This report records an examination of the radiological findings in the three groups of patients already mentioned. The clinical material consisted of fifty-nine patients with Reiter's disease, eighty-six with rheumatoid arthritis and fifty-four (all men) with ankylosing spondylitis, but the comparison was limited to those patients in whom certain specified joints were radiographed, independent of joint involvement: all these patients had routine radiographs of hands, feet, ankles (including the calcaneum) and pelvis. The radiographs were examined by two of the authors together (with a few isolated exceptions), from whom the clinical findings had been concealed. Under these circumstances the radiographs of 144 patients were available for comparison, of whom twenty-five had Reiter's disease, eighty-one had rheumatoid arthritis and thirty-eight had ankylosing spondylitis.

Table I shows the age distribution of the patients whose hands, feet, ankles and pelves

TABLE II

DISTRIBUTION OF THE PATIENTS STUDIED ACCORDING TO THE DURATION OF THE DISEASE

Duration in years	0–1		1–4		5–9		10 onwards	
	Number	Per cent	Number	Per cent	Number	Per cent	Number	Per cent
Reiter's disease	4	16	8	32	2	8	11	44
Rheumatoid arthritis	6	7	36	44	21	26	18	22
Ankylosing spondylitis			11	29	13	33	14	37

TABLE III

INCIDENCE AND DISTRIBUTION OF RADIOLOGICAL CHANGES

			Reiter's disease		Rheumatoid arthritis		Ankylosing spondylitis	
			Number	Per cent	Number	Per cent	Number	Per cent
Sacro-iliitis	Bilateral		8	32	8	10	38	100
	Unilateral		0	0	10	12	0	0
Periosteal new bone formation	Malleoli		12	48	41	50	12	31
	Tarsals		4	16	21	26	1	3
	Metatarsals		2	8	1	1	3	8
	Metacarpals		0	0	0	0	0	0
	Phalanges (hand)		2	8	8	10	0	0
	Phalanges (foot)		0	0	3	4	1	3
	Wrist		4	16	4	5	2	5
	Pelvis		1	4	0	0	4	11
Calcaneal changes	Periostitis	Posterior	6	24	17	21	4	11
		Plantar	5	20	3	4	2	5
	Spur	Posterior	8	32	12	15	2	5
		Plantar	10	40	32	39	9	24
	Erosion	Posterior	7	28	14	17	7	18
		Plantar	1	4	3	4	1	3
Peripheral arthropathy	Hands		7	28	66	81	4	11
	Feet		12	48	62	76	9	24

were radiographed, with a similar pattern throughout and no special bias towards any one age group so far as this radiological study is concerned. Table II gives the distribution of patients studied according to the duration of the disease.

INCIDENCE AND DISTRIBUTION OF RADIOLOGICAL CHANGES

The following radiological features were recorded using the criteria described by Murray *et al.* (1958).

Sacro-iliitis—This was noted as bilateral or unilateral, equivocal or unequivocal. Sacro-iliitis in the present report refers only to those recorded as unequivocal.

Periosteal new bone—This was looked for on the bones of the pelvis, wrists, hands, fingers, ankles, feet and toes.

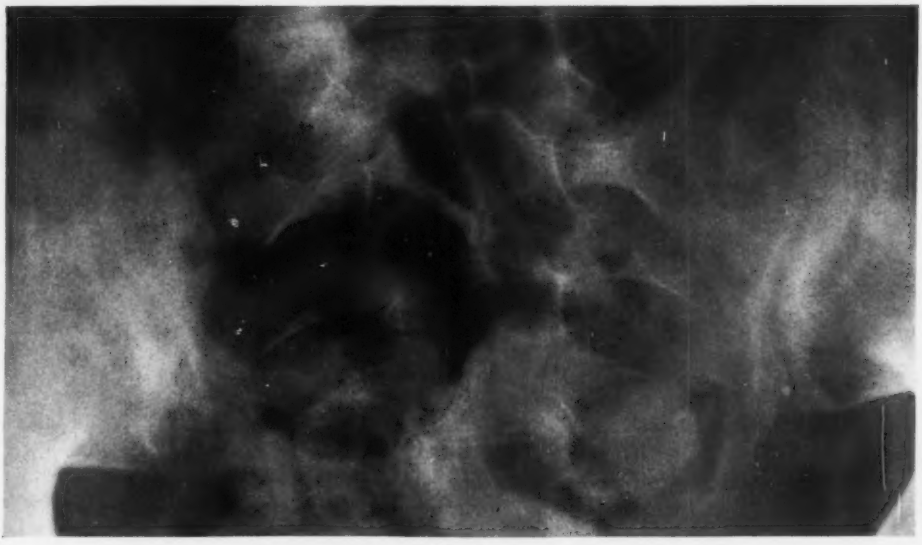

FIG. 1

The sacro-iliac joints in Reiter's disease, showing mild changes with loss of cortex, widening, minimal erosions and sclerosis.

FIG. 2

The sacro-iliac joints in rheumatoid arthritis, showing loss of cortex, slight widening, mild erosions and moderate sclerosis.

Calcaneal spur formation—This was distinguished as far as possible from periosteal new bone. Erosions were also recorded, posterior and plantar sites being noted separately.

Peripheral arthritis—Destructive changes in hands, wrists and feet were recorded together with their distribution, both as between hands and feet and within the hand itself.

Osteoporosis was not analysed. Kellgren and Lawrence (1957) have recently commented on the observer error which may arise in assessing lesser degrees of osteoporosis.

The incidence and distribution of these lesions is shown in Table III.

SACRO-ILIITIS

Unequivocal bilateral sacro-iliitis was seen in eight out of the twenty-five patients with Reiter's disease (32 per cent) compared with eight out of eighty-one with rheumatoid arthritis (10 per cent) and in all the thirty-eight patients suffering from ankylosing spondylitis (100 per cent). Unilateral sacro-iliitis was seen in ten, or 12 per cent, of the patients with rheumatoid arthritis. That sacro-iliitis often occurs in rheumatoid arthritis is well recognised (Sharp 1957).

FIG. 3

The sacro-iliac joints in ankylosing spondylitis, showing mild changes with loss of cortex, apparent widening and minimal sclerosis.

Unilateral sacro-iliitis was not seen in any of the patients with Reiter's disease or ankylosing spondylitis in this series, although it has been found in several other patients with Reiter's disease not included here because the radiological survey was incomplete. When the changes in the sacro-iliac joints were mild we were unable to distinguish any qualitative difference between the three diseases (Figs. 1 to 3), but severe erosions, marked sclerosis and particularly ankylosis were found only in Reiter's disease and ankylosing spondylitis (Figs. 4 and 5). Sharp (1957) on the other hand stated that he had observed fusion of the sacro-iliac joints in rheumatoid arthritis. Differences in the time of development of sacro-iliitis were, however, found (Table IV). The incidence of sacro-iliitis increased to 54 per cent in the patients with Reiter's disease with a history of five years or more, but in the patients with rheumatoid arthritis with a similar history the incidence increased to only 15 per cent.

PERIOSTEAL NEW BONE

We had formed the clinical impression that periosteal new bone was more commonly found in Reiter's disease than in the other disorders, but our findings in this comparatively

small series do not strongly support this, certainly so far as the incidence rather than the quality of the periostitis is concerned (Table III). Malleolar periosteal new bone was observed in half of the patients with Reiter's disease and rheumatoid arthritis and in one-third of those

FIG. 4
Reiter's disease in a patient with a fifteen-year history, showing ankylosis of the sacro-iliac joints.

FIG. 5
Advanced ankylosis of sacro-iliac joints in ankylosing spondylitis.

with ankylosing spondylitis (Figs. 6 to 8). Tarsal periostitis was seen in only one patient with ankylosing spondylitis and in one-quarter or less of those with rheumatoid arthritis or Reiter's disease. It was uncommon elsewhere although the incidence of 16 per cent in the wrists of

TABLE IV

INCIDENCE OF BILATERAL SACRO-ILIITIS IN REITER'S DISEASE CORRELATED WITH THE DISEASE DURATION AND COMPARED WITH SIMILAR FINDINGS IN RHEUMATOID ARTHRITIS AND ANKYLOSING SPONDYLITIS

Duration of disease .	Less than five years		More than five years	
	Number	Per cent	Number	Per cent
Reiter's disease . .	1 out of 12	8	7 out of 13	54
Rheumatoid arthritis .	2 out of 42	5	6 out of 39	15
Ankylosing spondylitis	11 out of 11	100	27 out of 27	100

patients with Reiter's disease was three times as common as in rheumatoid arthritis. It was found difficult to interpret accurately the periosteal new bone about the pelvis, particularly as our patients were drawn from the heavy labouring class of east London. Thus the distribution of periosteal new bone outside the calcaneum does not seem to be a differentiating factor, although florid, fluffy periosteal new bone does appear to be a feature of Reiter's disease and of ankylosing spondylitis, where it is seen characteristically in the pelvis and wrist; we have not seen this appearance in rheumatoid arthritis.

FIG. 6

FIG. 7

FIG. 8

Figure 6—Malleolar new bone formation in Reiter's disease. Compare with Figure 7 which shows a similar formation in rheumatoid arthritis and in ankylosing spondylitis in Figure 8.

THE CALCANEUM

Calcaneal spurs were of two types, a simple form (Figs. 9 to 11) in which the margin was clearly defined and which was not associated with changes beyond the base of the spur, and a fluffy form in which the spur was irregular and associated with periosteal new bone elsewhere on the calcaneum, especially on the plantar surface (Figs. 12 to 17). The simple spur appears to be an ossification in the attachment of the fibres of the long plantar ligament, whereas periostitis is a more diffuse process leading to thickening, increased density and the production of a fluffy outline of the plantar surface of the tuberosity and the plantar surface beyond it. In some cases it appears that this periostitis was laid down on a pre-existing simple spur (Fig. 13). Clearly further careful study of the radiological appearance and natural history of spurs and spur formation is required. Simple plantar spurs were observed commonly in all three groups (Table III), in 40 per cent of the patients with Reiter's disease, 39 per cent of those with rheumatoid arthritis and 24 per cent of those with ankylosing spondylitis.

Posterior spurs were, however, commoner in Reiter's disease with an incidence of 32 per cent compared with 15 per cent in rheumatoid arthritis and 5 per cent in ankylosing spondylitis. Periostitis of the posterior aspect of the calcaneum occurred in 24 per cent of the patients with Reiter's disease, in 21 per cent of those with rheumatoid arthritis and in 11 per cent of those with ankylosing spondylitis, but these differences are not significant. On the plantar surface, however, the incidence was significantly different ($P<0.01$), periostitis occurring in 20 per cent of the patients with Reiter's disease and in only three patients (4 per cent) with rheumatoid arthritis and two (5 per cent) with ankylosing spondylitis. The five patients with rheumatoid arthritis or ankylosing spondylitis were, therefore, carefully reviewed and the accuracy of the diagnosis was critically re-examined.

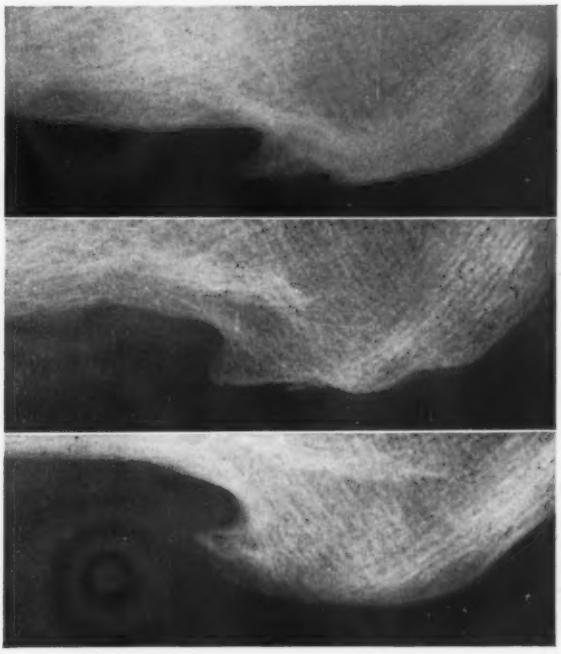

FIG. 9
A "simple" form of calcaneal spur in Reiter's disease.

FIG. 10
Spur in rheumatoid arthritis.

FIG. 11
Spur in ankylosing spondylitis.

CASE REPORTS

Case 151—A patient aged twenty-one was, six years previously, kicked on the back of the left heel. The injury led to severe pain which prevented walking for many months and which was treated with a below-knee plaster. No relief from pain was gained, and after four years a swelling on the back of the heel was treated by an operation, probably to remove a "spur." Involvement of the metatarso-phalangeal joints followed with low backache later; there was no urethritis or other genito-urinary symptoms. The radiographs showed bilateral sacro-iliitis, and prostatic fluid contained clumps of leucocytes. Treatment with radiotherapy gave a moderate response.
Comment—This patient was diagnosed as having ankylosing spondylitis but may have had an atypical spondylitis.

Case 158—A patient aged forty-three had been operated upon for claw toes secondary to poliomyelitis affecting the right leg. A left calcaneal spur had been treated by operation; in 1949 he had been treated for conjunctivitis. Clinically a stiff lumbar spine was found and radiographs showed a mild sacro-iliitis with considerable anterior and lateral bridging of the lumbar vertebrae. Genital examination revealed a chronic prostatitis.
Comment—This patient, who had also been diagnosed as having ankylosing spondylitis, perhaps had an atypical spondylitis.

Case 127—A patient aged thirty-three had sero-positive rheumatoid arthritis with nodules, including one over the calcaneal tendon. The severe progressive arthropathy was treated with steroids. The radiographs showed equivocal unilateral sacro-iliitis. There was also a marked chronic non-specific prostatitis with early-morning non-gonococcal urethral discharge.

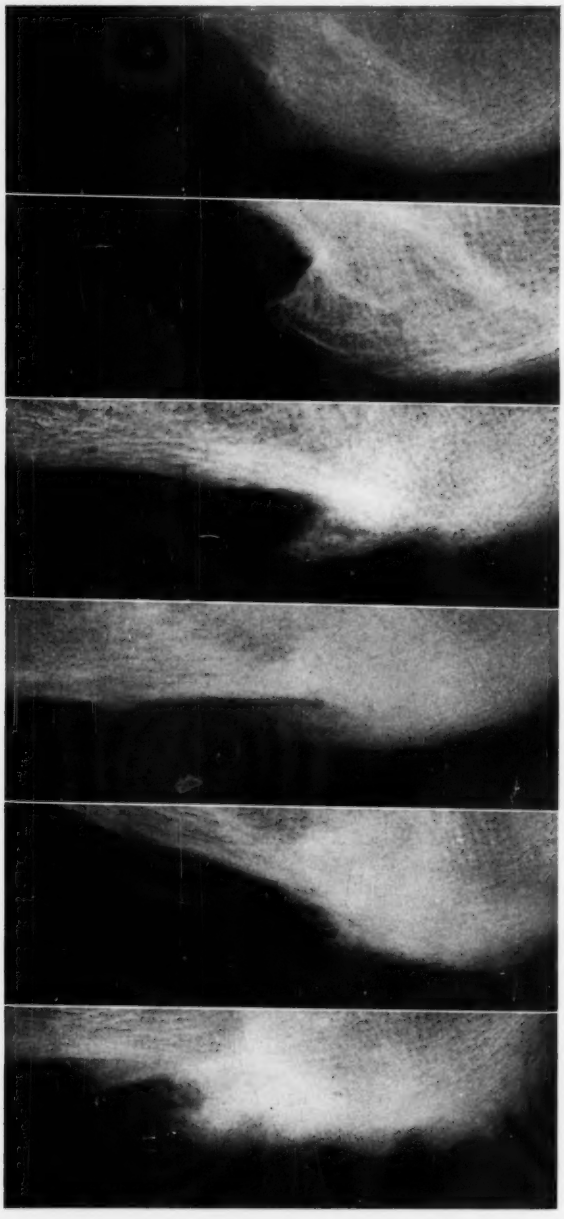

FIG. 12
Calcaneal periosteal new bone in Reiter's disease, shown as an early reaction on the plantar surface.

FIG. 13
New bone in Reiter's disease, apparently superimposed on a pre-existing simple spur.

FIG. 14
Reiter's disease. An irregular spur is associated with periosteal new bone.

FIG. 15
Reiter's disease. An irregular spur is associated with periosteal new bone.

FIG. 16
Reiter's disease. Multiple plantar spurs associated with periosteal new bone formation.

FIG. 17
Reiter's disease. A late stage with exuberant periosteal new bone, irregular spurring and increased density.

Comment—Although this patient had been classified as having rheumatoid arthritis, it is thought that Reiter's disease was present as well.

Case 122—A patient aged fifty-six who had sero-negative rheumatoid arthritis and who refused prostatic

massage (our only patient to do so) showed bilateral sacro-iliitis and a fluffy periostitis at the wrist in the radiographs.
Comment—Classified as rheumatoid arthritis, the diagnosis could be Reiter's disease.

Case 123—A patient aged fifty-seven with sero-negative rheumatoid arthritis had radiographs showing bilateral sacro-iliitis; he also had a marked chronic prostatitis.
Comment—Again classified as rheumatoid arthritis, the diagnosis could be Reiter's disease.

Thus in only one of these five patients (Case 127) is the diagnosis beyond suspicion. It seems that plantar periostitis of the calcaneum is very strongly suggestive of Reiter's disease and that it is this process which gives rise in some patients to the fluffy dense spurred calcaneum which is so striking a feature of this condition.

Erosions of the calcaneum, especially on its posterior aspect, occurred in all three groups (Figs. 18 to 20). The appearance resembled that described by Bywaters (1954), the incidence in Reiter's disease being 28 per cent, in ankylosing spondylitis 18 per cent and in rheumatoid arthritis 17 per cent.

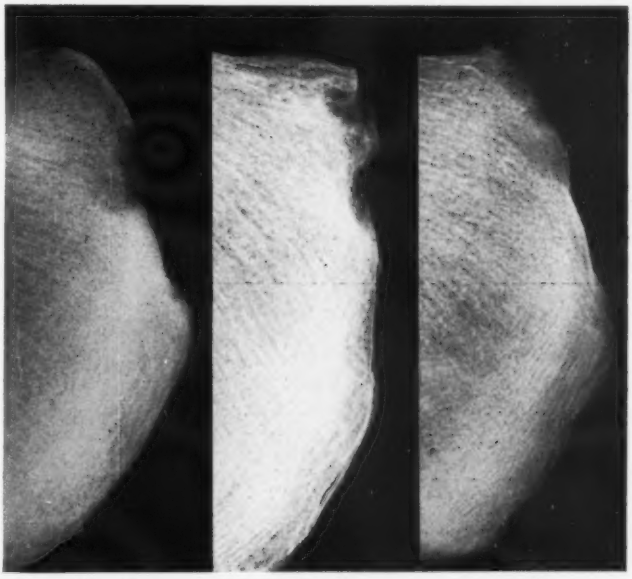

FIG. 18 FIG. 19 FIG. 20

Figure 18—Compare this posterior calcaneal erosion in Reiter's disease with that in rheumatoid arthritis shown in Figure 19 and ankylosing spondylitis in Figure 20.

PERIPHERAL ARTHROPATHY

Table III shows the preponderance of foot involvement over hand in both Reiter's disease and ankylosing spondylitis compared with rheumatoid arthritis; in the latter disease the hands and feet are affected radiologically in approximately equal proportions. The feet are more commonly and generally much more severely affected than the hands in Reiter's disease, and when the hands are affected the feet may be expected to show severe changes. Severe foot changes may be present, however, with normal or mildly affected hands in Reiter's disease. This is not a feature of rheumatoid arthritis.

Table V analyses all the hands that were radiographed in the material from which this series was drawn, and therefore includes additional patients to those fully covered radiologically. Only six patients with ankylosing spondylitis showed hand changes and have not been analysed.

TABLE V

DISTRIBUTION AND INCIDENCE OF LESIONS IN THE HAND, SHOWING THE INCIDENCE IN THOSE PATIENTS IN WHOM THE HAND IS ABNORMAL

Diagnosis	Rheumatoid arthritis		Reiter's disease	
	Number	Per cent	Number	Per cent
Total number radiographed	81		32	
Number showing hand changes	66		18	
Periostitis of radius and/or ulna	4	6	7	39
Erosion of radius and/or ulna	54	81	11	61
Periostitis of carpus	2	3	2	11
Destruction of carpal joints	42	63	6	33
Periostitis of metacarpals	3	4	2	11
Erosion of metacarpal heads	48	72	6	33
Narrowing of metacarpo-phalangeal joint	54	81	2	11
Narrowing of proximal interphalangeal joint	60	90	7	39
Erosion of proximal interphalangeal joint	56	84	7	39
Narrowing of distal interphalangeal joint	28	42	3	17
Erosion of distal interphalangeal joint	36	54	9	50
Deformity	14	21	1	6

In Reiter's disease changes in the hands are not only less common than in rheumatoid arthritis but they are also milder or more sporadic, and the individual hands show less numerous lesions. The wrists may show occasionally severe changes in Reiter's disease with destruction (Fig. 21), sometimes with fluffy periostitis (Fig. 22), and ankylosis with deformity was observed in one case (Fig. 23). In the past this appearance would probably have been described as typical of gonococcal arthritis. Severe wrist changes are more often seen in rheumatoid arthritis and linear periostitis of the ulna and radius may look similar in both (Figs. 24 and 25), but of the patients with rheumatoid arthritis only two showed fluffy periostitis of the wrist: one was sero-negative and had chronic prostatitis; the other was also sero-negative and refused prostatic massage (Case 122 already described). Ulnar deviation of the fingers was not seen in Reiter's disease, nor was generalised osteoporosis in the hand. In comparing the incidence of the involvement of the various joints in the hand destructive changes predominated in the proximal interphalangeal joint in rheumatoid arthritis in 84

FIG. 21

FIG. 21

The wrist and hand in a patient with Reiter's disease showing severe wrist and carpal changes with periosteal new bone formation at the bases of the metacarpals. There is relatively mild interphalangeal joint involvement and the metacarpo-phalangeal joints are spared.

FIG. 22

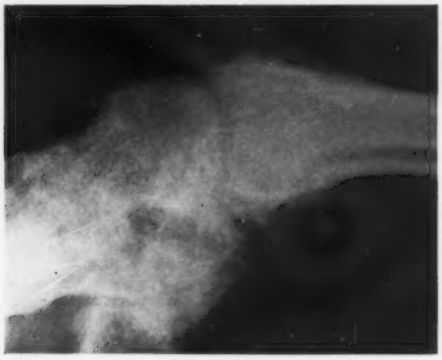

FIG. 23

Figure 22—Fluffy periostitis of the wrist in Reiter's disease. Figure 23—Fluffy periostitis and ankylosis in deformity of the wrist in Reiter's disease.

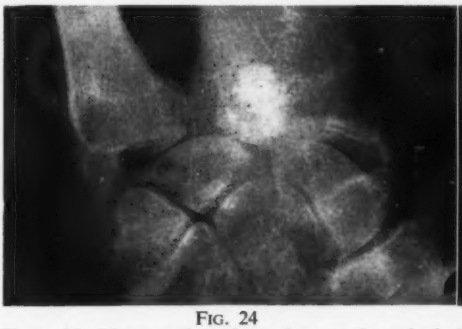

FIG. 24

FIG. 25

Figure 24—Linear periosteal new bone at the wrist in Reiter's disease. Compare with Figure 25, showing a similar condition in rheumatoid arthritis.

per cent compared with 39 per cent in Reiter's disease; destructive changes were also seen more commonly in the metacarpo-phalangeal joint in rheumatoid arthritis, but the most striking difference was in narrowing of the metacarpo-phalangeal joints. It was relatively rare in Reiter's disease (11 per cent) but was observed in 81 per cent of the cases of rheumatoid arthritis. In ankylosing spondylitis the hand lesions are rare but they seem to follow the same pattern as in Reiter's disease.

DISCUSSION

We have found no absolute means of differentiating the conditions radiologically in all cases; indeed some patients have had repeated attacks of Reiter's disease without showing radiological change. But we believe that in many patients help can be given by radiology and we suggest that the following points might be helpful.

Reiter's disease—The changes are predominantly in the feet and sacro-iliac joints. In the feet, in addition to destructive joint changes and consequent deformity, exuberant (as opposed to simple linear) periosteal new bone formation tends to occur at the calcaneum, and it may also occur to a lesser extent at the wrist. Asymmetrical bone and joint involvement is a characteristic but not invariable feature whereas generalised osteoporosis is not. Hand changes are mild, even when the wrist is severely involved. We consider that the presence of large rough spurs with fluffy periosteal new bone on the plantar surface of the calcaneum is characteristic of Reiter's disease.

Rheumatoid arthritis—The generally accepted appearance in rheumatoid arthritis—that is, a tendency to be symmetrical, to be associated with osteoporosis and to affect hands and feet equally—is confirmed. The sacro-iliac joints, when affected, show only mild changes.

Ankylosing spondylitis—Some patients with Reiter's disease have been seen to develop an

" ankylosing spondylitis," and some patients with ankylosing spondylitis cannot be differentiated radiologically. In most patients with ankylosing spondylitis the great predominance and early appearance of sacro-iliac changes and the mild involvement of the feet is in contrast to the severe affection of the feet and late development of sacro-iliitis in Reiter's disease.

CONCLUSIONS

1. Sacro-iliitis is a common radiological finding in Reiter's disease: it develops slowly and is present in over half the patients with a history of five years or more. We are not so far able to distinguish any qualitative difference between the three diseases with early changes, without considering the relationship of the sacro-iliitis to spondylitic changes in the spine and to the duration of disease, but advanced changes were not seen in rheumatoid arthritis.
2. Florid periostitis is very suggestive of Reiter's disease, and when it occurs on the plantar aspect of the calcaneum it is probably pathognomonic. Simple spurring and erosion of this bone as defined here was present in all three groups.
3. Certain differences appear in the radiological appearances of the hands and feet, but a radiological distinction may be extremely difficult on the basis of these alone, apart from the periostitis mentioned above.

SUMMARY

The radiological appearances in twenty-five patients with Reiter's disease have been compared with those in eighty-one with rheumatoid arthritis and thirty-eight with ankylosing spondylitis. The similarities and differences have been analysed. Changes of periosteal new bone in the calcaneum appear to be the only significant differentiating factor, although minor differences in incidence and distribution occur elsewhere. Sacro-iliitis is a common radiological feature of long-standing Reiter's disease.

We would like to record our thanks to Miss P. H. Burgess, A.R.P.S., for her help in preparing the radiographic reproductions.

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CUBO-NAVICULAR SYNOSTOSIS

A Rare Tarsal Anomaly

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Although tarsal anomalies have been known for years, their correlation with spastic flat foot has drawn special attention to them. Calcaneo-navicular fusion and talo-calcaneal bridge are the most important, and then comes talo-navicular synostosis. Rare cases of cuneo-cuboid, cuneo-metatarsal and calcaneo-cuboid fusion have been reported, but we have found only one reference to cubo-navicular coalition (Waugh 1957) and in that case the fusion was incomplete. The following case, which we encountered in 1955, seems to be the first reported example of complete cubo-navicular fusion.

FIG. 1

FIG. 2

Figure 1—Left foot, showing complete cubo-navicular fusion. Figure 2—Right foot, showing cubo-navicular synchondrosis.

CASE REPORT

A man of forty-three sustained mild violence to both feet. Examination did not show any evidence of important damage. Only moderate cavus deformity was noted, with slight limitation of inversion and eversion.

Radiographs disclosed a complete cubo-navicular synostosis in the left foot and a synchondrosis in the right.

Pain disappeared after a few days' rest. There was no sign of peroneal spasm.

Comment—Although the radiographic appearance of our patient's right foot was like that of Waugh's (1957) patient the clinical picture was different.

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NAVICULO-CUNEIFORM SYNOSTOSIS

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Abnormal coalition between tarsal bones is well recognised as a cause of pain in the foot. Not all such coalitions give trouble. In the case recorded below there were radiological signs suggestive of a synostosis but the patient had never had flat foot nor had he ever had pain in his feet or legs.

Case report—The patient was a middle-aged man who sustained a fracture of the medial malleolus in an accident. When the radiographs were examined one noticed, apart from the fracture, a small flake-like piece of bone on the dorsal aspect of the navicular bone. It did

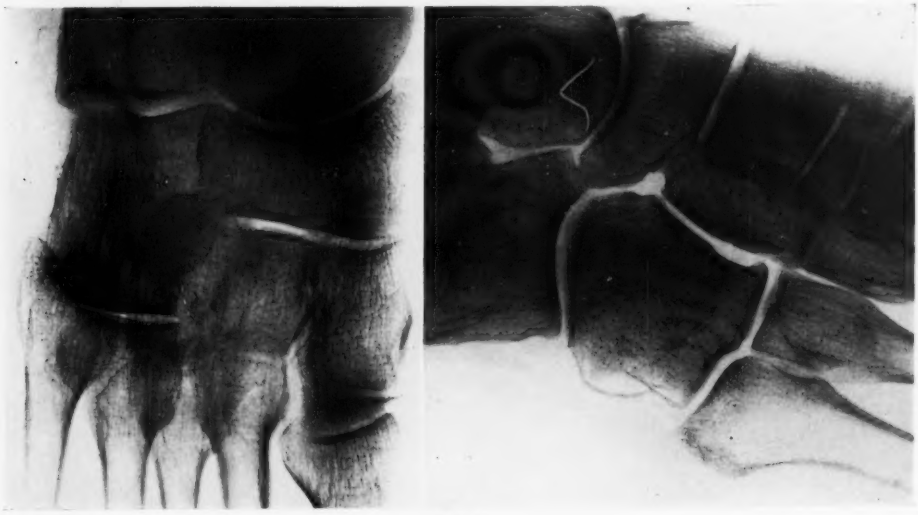

FIG. 1

not seem to have the appearance of a chip fracture, and further radiographs of the foot were obtained to see if indeed a synostosis were present. These showed a solid bar of bone connecting the navicular bone to the lateral cuneiform bone (Fig. 1). There was no abnormality in the other foot.

Comment—No other report of such a synostosis has been found.

A AND B ANTIGENS IN HUMAN BONE TISSUE

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Antigens A and B have been demonstrated in human epidermis by Coombs, Bedford and Rouillard (1956) and by Nelken, Gurevitch and Neuman (1957), and in human corneal tissues by Nelken, Michaelson, Nelken and Gurevitch (1956). Furthermore it has been shown that these antigens are identical with those of the red blood cells. Sloughing of homogenous skin grafts and clouding of corneal transplants has been shown to be due to an antigen-antibody reaction, though the significance of A and B antigens in these reactions is still unsettled. Since it is known that transplanted homogenous bone may sometimes undergo resorption or delayed incorporation of the graft into the host bone, suspicion has arisen that failure of bone transplantation may sometimes be due to an antigen-antibody reaction. Curtiss and Herndon (1956) observed the development of anti-red-cell agglutinins in dogs after homogenous bone transplantation. Experiments were therefore undertaken to find out whether A and B antigens are present in human bone.

METHOD OF EXPERIMENTS

Selection and preparation of bone—Pieces of normal human bone weighing from two to six grammes were removed at operation from tibia, ribs, sacrum and phalanges. The bones were studied in their fresh state or after storage for up to eight weeks at a temperature of −20 degrees centigrade. The blood groups of the donors were determined. The bones were stripped of all soft tissue and periosteum, and were then split so that the cancellous bone could be separated by scraping it out of the cortical bone. The cancellous bone was shaken in a Mickle tissue disintegrator for five minutes in twenty millilitres of saline using carborundum as abrasive material, the washing being repeated three times. The hard residue consisted of washed cancellous bone, and the centrifugal sediment of the washing fluid represented the soft elements of cancellous bone. Thus three types of bone substance were available for examination: soft elements of cancellous bone, hard elements of washed cancellous bone and hard cortical bone.

Preparation of antigenic material—The cortical bone was fragmented, washed three times for ten minutes in a tissue disintegrator with carborundum and then ground in a kitchen blender, the resultant fine granular deposit serving as the antigenic cortical material. Microscopic examination showed that these fine particles, measuring 7–10μ, had none of the normal microscopic structure of bone. The hard washed cancellous bone was ground in a kitchen blender and the resulting fine granular material served as the antigenic material of hard cancellous bone. In order to examine whether traces of blood remained in the antigenic material the Benzidine test was performed. Both the cancellous and the cortical bone gave a negligible reaction, only minute green traces being present and the supernatant fluid remaining colourless; but the soft elements of cancellous bone showed a markedly positive Benzidine test.

Preparation of sera—Blood serum from healthy human adults with a known high titre of anti-A and anti-B antibodies (not less than 1 : 128) was used. The sera were inactivated by heating at 56 degrees centigrade for thirty minutes. The serum titre was estimated by the double serial dilution method against a freshly prepared 2 per cent erythrocyte suspension. The results were read at room temperature after thirty minutes. The last dilution to show microscopic agglutination determined the titre.

EXPERIMENTS

Adsorption—0·5 millilitres packed antigen material was incubated in 0·5 millilitres of antiserum diluted with an equivalent amount of normal saline. Adsorption was allowed in siliconed tubes, to prevent adherence of bone particles to the glass, for eight hours at a temperature of 6 degrees centigrade, the tubes being shaken every thirty minutes.

Elution—Eluates were prepared from the adsorbates at 56 degrees centigrade according to the method described by Gurevitch and Nelken (1955).

Titration of isoagglutinins—After the adsorption and elution experiments the sera were again titrated by the double serial dilution method against a freshly prepared suspension of red cells of the blood group. Before and after adsorption the sera were titrated against the same suspension of red blood cells by the same technician. These experiments were repeated thirty-three times. Similar results were obtained each time (Table I).

TABLE I

RESULTS OF ADSORPTION AND ELUTION EXPERIMENTS

Source of antigenic material	Blood group of donor	Titre of O serum before adsorption		Titre of O serum after adsorption		Titre of eluate	
		Anti-A	Anti-B	Anti-A	Anti-B	Anti-A	Anti-B
Soft elements of cancellous bone	O	1:64	1:64	1:64	1:64	0	0
	A	1:64	1:64	0	1:64	1:8	0
	B	1:64	1:64	1:64	1:8	0	1:8
	AB	1:64	1:64	0	1:2	1:4	1:8
Hard elements of washed cancellous bone	O	1:64	1:64	1:64	1:64	0	0
	A	1:64	1:64	1:16	1:64	1:4	0
	B	1:64	1:64	1:64	1:32	0	1:2
	AB	1:64	1:64	1:16	1:32	1:2	1:2
Hard cortical bone	O	1:64	1:64	1:64	1:64	0	0
	A	1:64	1:64	1:64	1:64	0	0
	B	1:64	1:64	1:64	1:64	0	0
	AB	1:64	1:64	1:64	1:64	0	0

RESULTS

Soft elements of cancellous bone—The titre of the antiserum was definitely reduced. When material from Group A donors was used the anti-A titre of the O serum was reduced, while the anti-B titre remained unchanged. When material from B donors was used only the anti-B titre was reduced. When material from AB donors served as antigenic material, both anti-A and anti-B titres were reduced. Material from donors of blood group O did not reduce either the anti-A or anti-B titre. Eluates prepared from the adsorbates agglutinated red blood cells of the corresponding group.

Hard elements of washed cancellous bone—The results were similar to those for the soft elements but the titre reductions were less pronounced.

Hard cortical bone—No reduction whatsoever could be detected in the titre of the adsorbed serum. Even repeated adsorptions did not reduce the titre of the antiserum. Eluates prepared from the adsorbates did not agglutinate the red blood cells of the corresponding group.

DISCUSSION

These experimental studies show that cortical bone has no antigenic activity whatsoever; it did not reduce the anti-A or anti-B agglutinins of the adsorbed serum. This suggests that antigens A and B are absent from cortical bone. The Benzidine test on this bone showed no more than a faintly positive reaction.

Washed hard cancellous bone showed marked antigenic activity. The Benzidine test on this bone showed a faintly positive reaction like that shown by cortical bone. Thus it seems improbable that this antigenic activity could be the consequence of contamination by bone marrow elements.

The soft elements of cancellous bone were antigenically most active; they were able to reduce the titre of an antiserum completely. It seems probable that this marked antigenic activity arises from the bone marrow content of the soft elements of cancellous bone.

SUMMARY

1. Sloughing of homogenous skin grafts and clouding of corneal transplants have been shown to be due to antigen-antibody reaction; antigens A and B have been demonstrated in human epidermis and corneal tissue; and anti-red-cell agglutination has been observed in dogs after homogenous bone transplantation. Human bone was therefore examined in thirty-three experiments to determine the presence or absence of A and B antigens.

2. The bone was separated into hard cortical bone, hard washed cancellous bone and soft-tissue washings of bone.

3. Adsorption experiments showed that A and B antigens are absent from cortical bone. A and B antigens are present in cancellous bone.

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EXPERIMENTAL EPIPHYSIAL INJURY AND FREIBERG'S DISEASE

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In Freiberg's original paper in 1914 on the condition that bears his name he reported six cases and described a definite history of injury in three; hence his term " infraction." In 1926 he described another case, in which, although the second metatarsal shaft was thickened, the gross radiological appearances of the metatarsal head were normal. Because of this case, which was hardly typical of the condition he first described, he was ready to acknowledge that " simple trauma is not a satisfying explanation of the clinical and roentgenographic phenomena." In sympathy with this, Köhler considered it altogether unlikely that trauma was an important etiological factor.

Smillie (1957) favoured the traumatic view, postulating stress rather than a single injury.

I have attempted to assess the linear strength of the second metatarsal and proximal phalanx at varying ages, and to ascertain the " weakest link in the chain."

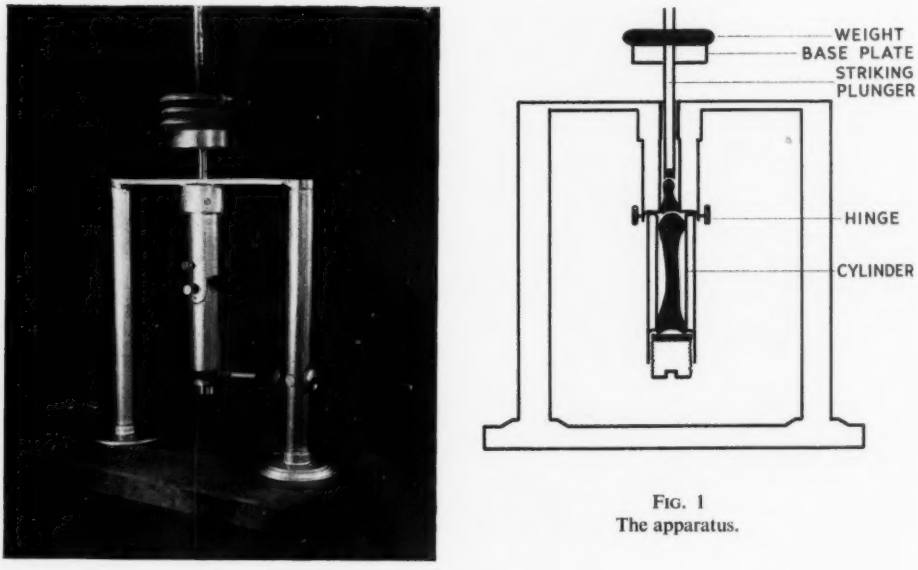

FIG. 1
The apparatus.

APPARATUS

The articulated metatarsal and phalanx were placed in a cylinder (Fig. 1) containing a striking plunger which rested on the head of the phalanx. Weights were dropped from varying heights on to a base plate affixed to the plunger, the force thus being transmitted through the plunger, phalanx, metatarso-phalangeal joint and metatarsal. A hinge adjustment was provided at the level of the metatarso-phalangeal joint so that the phalanx and metatarsal could be accurately aligned.

MATERIAL

Fresh necropsy specimens of the second metatarsal and proximal phalanx were dissected out with care to avoid damage to the metatarso-phalangeal joint. They were removed from both feet. The subjects had normal skeletons, being dead of acute illness or accident. Age and sex are shown in Table I.

PROCEDURE

After insertion of each specimen in the machine a 1 lb. weight was dropped from a height of three inches, and then from progressively greater heights up to twenty-one inches. The same procedure was repeated with 2 lb., 3 lb. and 4 lb., or until a fracture occurred. After each impact the metatarsal and phalanx were carefully inspected and the articular surfaces gently probed. A small hole in the plantar part of the capsule allowed an adequate view without causing instability.

TABLE I

DETAILS OF THE EXPERIMENTS

Specimen number	Age (*years*)	Sex	Effect on phalanx		Effect on metatarsal head		Weight (*lb.*)	Height (*inches*)
			Right	Left	Right	Left		
1	4½	F	Fracture	Fracture	—	—	3	12
2	5½	M	Fracture	Fracture	—	—	3	18
3	6½	M	Fracture	Fracture	—	—	3	21
4	6¾	M	Fracture	Fracture	—	—	3	18
5	8	F	Fracture	Fracture	—	—	4	18
6	10	M	Fracture	Fracture	—	—	4	12
7	11	M	Fracture	Fracture	—	—	4	18
8	12½	F	—	—	Fracture	Fracture	4	18
9	11	F	—	—	Fracture	Fracture	4	21
10	4 adults		Fracture	Fracture	—	—	4	18

It was necessary to transmit force through the proximal phalanx to the metatarsal head because, in this way, a striking surface (the base of the phalanx) was provided, which was congruous with and proportional in size to the metatarsal head.

A stress element was obviously introduced by repeated striking forces, but this was the same for each specimen.

OBSERVATIONS

1. The metatarsal epiphysis was the weakest component in specimens 8 and 9.

2. It was not possible to produce any grades of epiphysial damage. Either the epiphysis largely disintegrated or it remained intact. This is in conformity with the physical characteristics of a sphere.

3. In spite of gross comminution of the epiphysis radiographs showed little change (Figs. 2 and 3).

It is unlikely that the slight distortion in the lateral radiograph would be noticeable in a radiograph of the foot, of which a true lateral projection cannot be obtained.

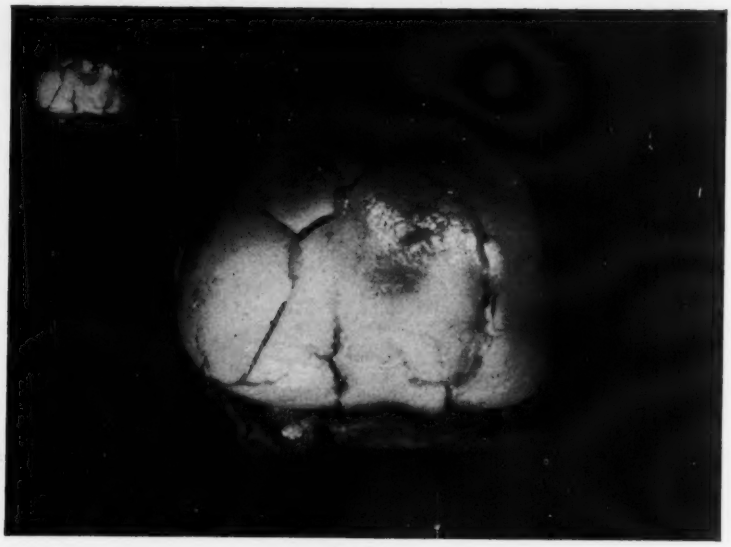

FIG. 2
Photograph of specimen 8 showing gross disruption of the articular surface but maintenance of its general shape.

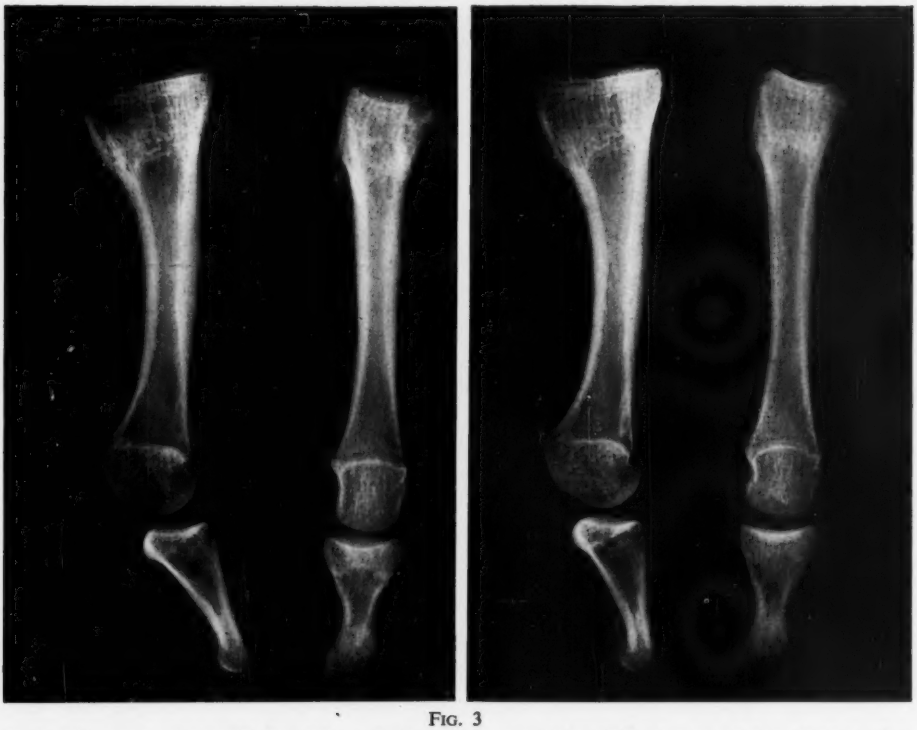

FIG. 3
On the left, second metatarsal before injury. *On the right*, same metatarsal after fracture of the articular surface by a 4 lb. weight dropped from eighteen inches.

DISCUSSION

Five cases of Freiberg's disease have been collected showing radiological appearances resembling those shown in Figures 5 to 7. Comparison of the radiographs in Figure 5 with that of the specimen in Figure 3 reveals a similar stage of epiphysial maturation. It seems an important observation that, in the experiment, the phalanx broke in all the specimens except in the two (specimens 8 and 9) in which the stage of epiphysial maturation compared closely with that seen in early Freiberg's infraction. In these two specimens the fracture of the metatarsal epiphysis suggests that it is relatively more fragile at this stage of maturation.

Freiberg's infraction occurs most commonly in the second, less commonly in the third and rarely in the fourth metatarsal. It is only occasionally bilateral.

The second is the most fixed metatarsal, the third rather less fixed and the fourth quite mobile. Because of its fixation, the second metatarsal would be likely to be affected more by

FIG. 4
Radiograph of foot in tiptoe position.

injury than those that are more mobile. The second metatarsal is also usually the longest metatarsal, although by no means always so in Freiberg's infraction.

In tiptoeing (Fig. 4) the metatarsals take weight vertically. The main direction of weight transmission is through the talus, the three cuneiform bones and the first three metatarsals, the second metatarsal forming the centre.

The increased density apparent on the radiograph is a very early change and probably due at this stage to the formation of callus in and around the fracture (Fig. 8).

The radiograph in Figure 7 shows hypertrophy of the metatarsal shaft in a year. This hypertrophy is only indirectly associated with the disease and may be ascribed to the increased stress on the second metatarsal caused by loss of dorsiflexion at the metatarso-phalangeal joint. This would explain the delay in its appearance.

Because of the degree of comminution postulated it is perhaps not surprising that small fragments are rendered avascular. Those fragments subjacent and attached to portions of

FIG. 5
Antero-posterior and lateral radiographs showing an early example of Freiberg's infraction in a girl of fourteen.

FIG. 6

FIG. 7
Figure 6—The same forefoot two months later. Figure 7—A year later.

the fissured articular cartilage never revascularise because they are able to obtain a new blood supply from only one surface. The necrosis and disintegration of this attached part probably accounts for the collapse shown in a section of a typical example of the late healed case (Fig. 9).

It seems strange that no fracture as such has ever been described in such a vulnerable epiphysis. It is proposed, as a result of this investigation, that Freiberg's infraction is indeed a fracture, although somewhat modified by its environmental epiphysial plate and articular cartilage.

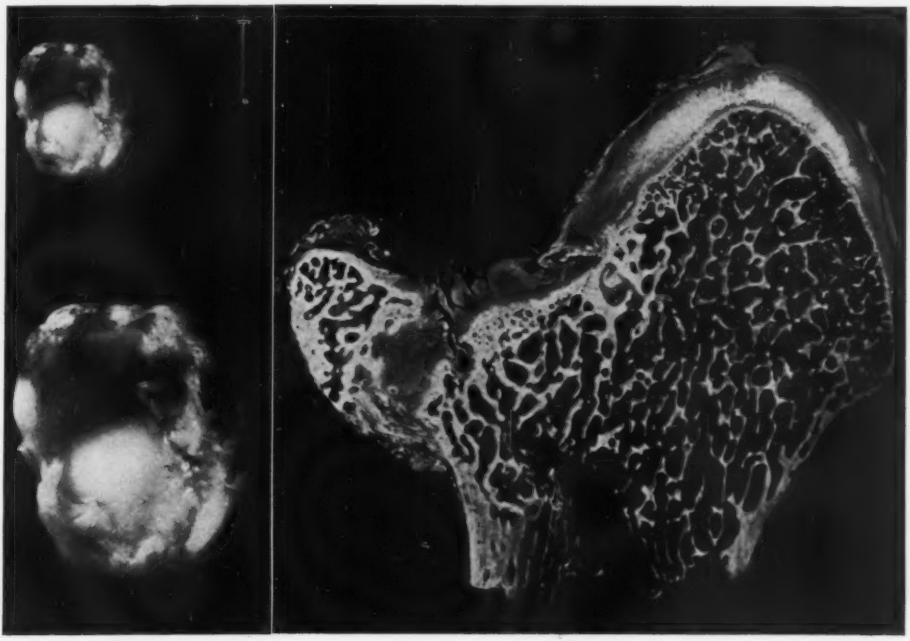

FIG. 8 FIG. 9

Figure 8—Enlarged photograph of articular surface of metatarsal head in the healed phase of Freiberg's infraction (shown actual size above). Figure 9—Section from specimen shown in Figure 8, showing collapse with the articular surface intervening between the flattened metatarsal head and the dorsal fragment.

SUMMARY

1. Experiments show relative weakness of the second metatarsal epiphysis at a certain stage of epiphysial maturation.

2. It is shown that at this stage Freiberg's infraction is likely to occur.

3. It has been demonstrated that even gross comminution with disruption of the articular cartilage of the second metatarsal head is compatible with a radiograph of almost normal appearance.

I am grateful to Mr H. Jackson Burrows for his helpful criticism of this paper and to Mr R. J. Whitley, of the Photographic Department of the Institute of Orthopaedics, for the illustrations.

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TRANSPLANTATION IMMUNITY IN BONE HOMOGRAFTING*

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The knowledge that homografts of many tissues have a limited period of survival, and the revival of the theory of tissue immunity (Gibson and Medawar 1943, Medawar 1944, 1945) makes it of interest to know how bone homografts compare with other tissues in this respect.

Since 1878 homografts of bone have been known to be clinically effective (Macewen 1912), and the introduction of the bone bank (Inclan 1942) has led to a great increase in their use. The role of tissue immunity reactions in bone homografting has received little attention until recently, and reliable information concerning cell survival and the source of bone formation in these clinically effective grafts is lacking.

The present study was undertaken to determine whether homografts of bone behaved in the same way as those of other tissues with respect to cell survival and the production of transplantation immunity, and to consider the importance of such a reaction if found to be present.

METHOD AND MATERIALS

It was decided to make a detailed histological comparison between autografts and homografts of bone, and also to study bone homografts in animals which had been "immunised" by means of a prior skin homograft from the same donor. Bone homografts which had been freeze-dried were to be compared with fresh material by a study of their histological progress: in addition to this the rejection times of subsequent skin homografts from the same donors were to be determined, the purpose being to demonstrate whether freeze-drying influences the behaviour of a bone homograft, or the reaction of the host tissues to it.

The experiments were carried out on rats 60 to 100 days old. Wistar albino and hooded strains were used so that homografts could be exchanged between strains: it was hoped in this way to avoid any "matching" of tissue antigens in host and donor.

The bone grafts were obtained from the proximal half of the ilium and had an average weight of 38 milligrams. After all soft tissue had been scraped off they were chipped into fragments about a millimetre long. The graft was placed in a slit made in the lumbar paravertebral muscles. An extra-skeletal site was used so that the progress of the graft would not be complicated by the inclusion of skeletal tissue from the host.

Freeze-dried bone was prepared by continuous evacuation over phosphorus pentoxide at −30 degrees centigrade for two weeks. This achieved drying to 1 per cent of the original water content.

Unless otherwise stated thirty-two rats were used in each series. Two rats were killed every second day until the eighteenth day, then at four, six and eight weeks and thereafter at monthly intervals to six months (in a few instances to one year). The number of animals at a particular period was sometimes increased when confirmation of some specific point was required, but the figures quoted in the text apply only to the numbers in the original series.

When the animals were killed a block of muscle containing the bone graft was excised

* This work was presented in part at the meeting of the British Orthopaedic Association held at Shrewsbury in May 1957, and at the meeting of the Orthopaedic Research Society held in New York in February 1958.

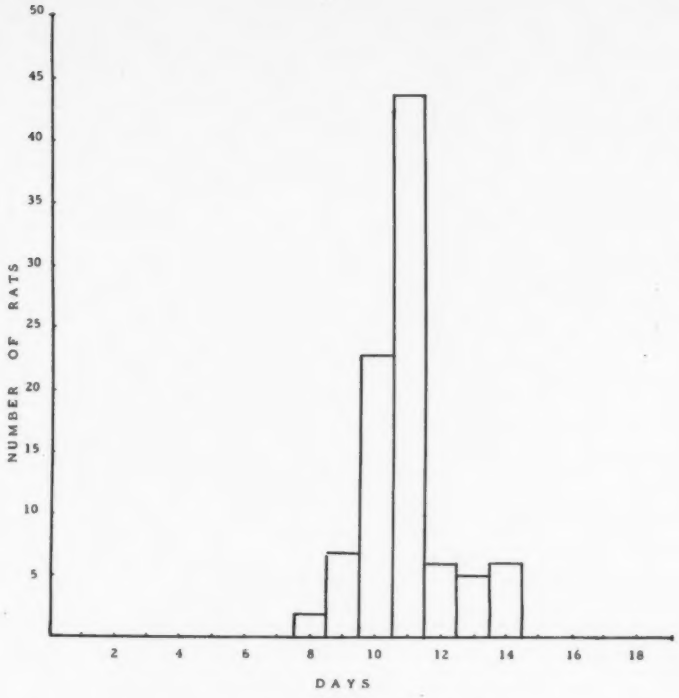


FIG. 1
Rejection times of first set skin homografts in rats.

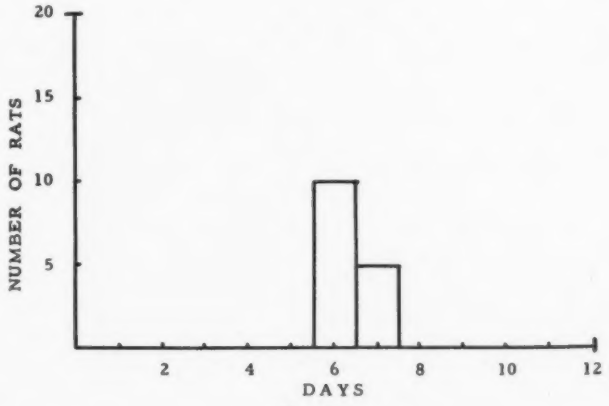


FIG. 2
Rejection times of second set skin homografts in rats.

and fixed in formalin. Paraffin sections were prepared after decalcification with neutral E.D.T.A.* and were stained with haematoxylin and eosin.

Skin grafts were carried out with minor modifications of the technique described for "fitted grafts" by Billingham and Medawar (1951) and Woodruff and Simpson (1955). A circular piece of skin about a centimetre in diameter was dissected off the panniculus carnosus of the lateral chest wall and sutured to a defect created by the removal of a similar graft on another rat. The graft was protected by a dressing of vaseline gauze and a plaster-of-Paris jacket.

A series of skin homografts was carried out to establish the rejection time using this technique. A mean survival time of 10·9 days was found in ninety-three grafts† (Fig. 1).

TABLE I

SERIES OF EXPERIMENTS

1. Bone autograft
2. Bone homograft in normal rats
3. (*a*) Bone homograft three weeks after skin homograft from the same donor (*b*) Bone homograft four months after skin homograft from the same donor
4. Bone homograft four weeks after bone homograft from the same donor
5. Freeze-dried bone homograft
6. Freeze-dried bone homograft four weeks after skin homograft from the same donor
7. Skin homograft three weeks after fresh bone homograft from the same donor
8. Skin homograft three weeks after freeze-dried bone homograft from the same donor

Second skin grafts to rats immunised fifteen to nineteen days before by skin homograft from the same donor underwent an earlier rejection, a mean survival time of 6·3 days being found with fifteen grafts (Fig. 2). Table I lists the series of grafts that were studied.

RESULTS

Series 1: Bone autograft—Apart from a few osteocytes which survived in some of the grafts, almost all the grafted bone died. This was evident from empty lacunae and intensely basophilic staining of any residual osteocyte nuclei. Organisation of the haematoma was complete in six to eight days.

At four days new woven bone began to appear on the surface of the graft fragments. This new bone grew vigorously, linking the graft fragments and extending into the surrounding connective tissue (Figs. 3 to 5). At fourteen days newly formed lamellar bone was seen for the first time; at sixteen days the new bone which had hitherto been arranged in a haphazard manner began to show organisation in irregular spheres or ossicles (Fig. 6). These structures were occupied by haemopoietic marrow from the beginning—even before their walls were complete—and they became progressively more regular in outline. They were elongated, their long axes corresponding with the direction of the adjacent muscle fibres (Figs. 7 and 8).

* Ethylene diamine tetra-acetic acid. The decalcifying solution is prepared by dissolving 250 grammes of the disodium salt of E.D.T.A. in 1,750 millilitres of distilled water, and adjusting the pH to 7·0 by the addition of sodium hydroxide.

† Recorded rejection times for first set skin homografts in rats by other workers: 8 days, Levinson and Necheles (1956); 8·1 days, Lehrfeld and Taylor (1953); 11·6 days, Rabinovici (1947); 13 days, Stark (1951); 13 to 14 days, Woodruff and Simpson (1955).

Nodules of cartilage developed in six of thirty-two graft sites (Fig. 9) and in one instance became incorporated in the wall of the ossicle. Osteoclastic resorption proceeded from the fourth day, removing dead graft and new bone which did not contribute to the ossicle. After the mature ossicle had formed little further osteoclast activity was seen. The dead tissue of the original graft was not always completely removed, being occasionally found incorporated in the wall of the ossicle (Fig. 8). The reaction of the host site to the graft consisted initially of rapid invasion of the haematoma by granulation tissue and round cells. This settled by eight days to a less vascular fibrous tissue which finally became a thin fibrous periosteum to the forming ossicle. All grafts in this series conformed to this pattern.

Series 2: Bone homograft in normal rats—Initially the findings were very much the same as those described for autografts in Series 1. Only a few osteocytes could be identified in the grafted bone. Granulation tissue rapidly extended through the graft area. New bone appeared

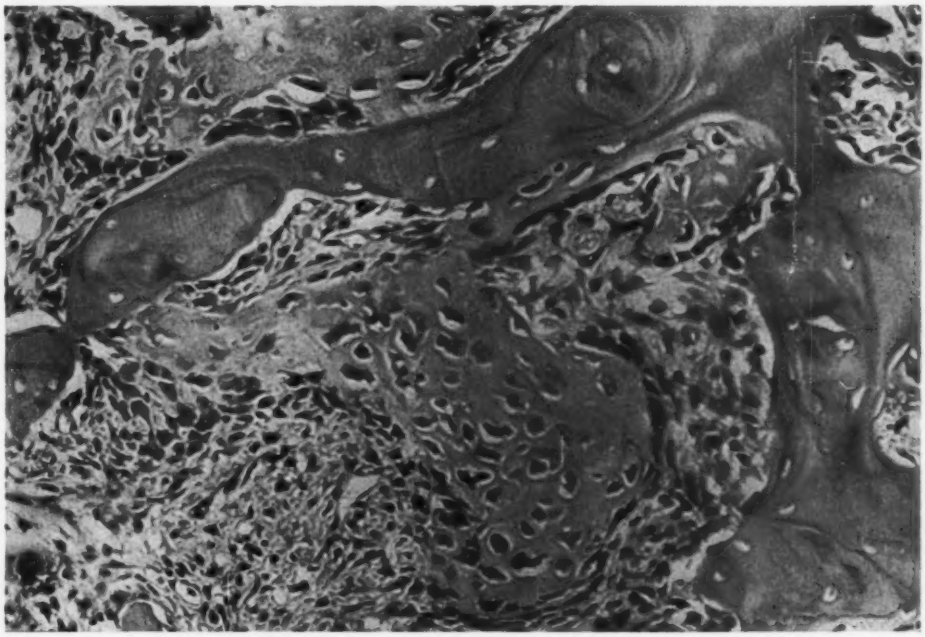


FIG. 3

Autograft, six days (×315). The lacunae of the graft are empty, or contain only shrunken remnants of osteocytes. New bone has begun to grow on the surface of the graft and is extending into the surrounding connective tissue.

on the graft surface at four to six days and grew until eight days (Fig. 10). In contrast to the autograft, this new bone formation, although variable in amount, was usually scanty: in three of fourteen grafts of six to eighteen days' duration it could not be identified.

After eight days the progress was entirely different from that of the autograft. The surface layer of osteoblasts on the new bone became flattened and more basophilic and quickly disappeared (Figs. 11 and 12). The deeper osteocytes of the new formed bone also became pyknotic and fragmented (Figs. 12 and 13) and in their turn, disappeared. In those grafts in which a large amount of new bone was produced, the dissolution of the bone cells was frequently delayed until sixteen or even eighteen days (Fig. 14). Death of this new bone left a characteristic vacuolated bone matrix, the empty lacunae of the immature bone being large in comparison with the amount of matrix. This enabled the early phase of new bone

FIG. 4

Autograft, ten days (×315). The original graft is largely acellular. There is vigorous proliferation of new bone from the graft surface.

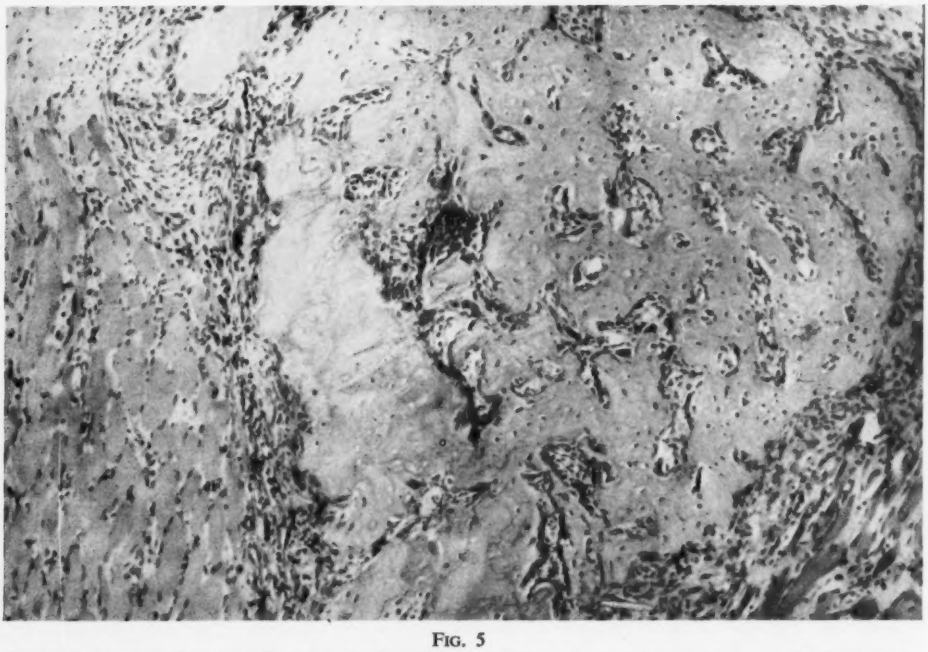


FIG. 5

Autograft, fourteen days (×105). Growth of new bone continues. Its arrangement appears quite haphazard.

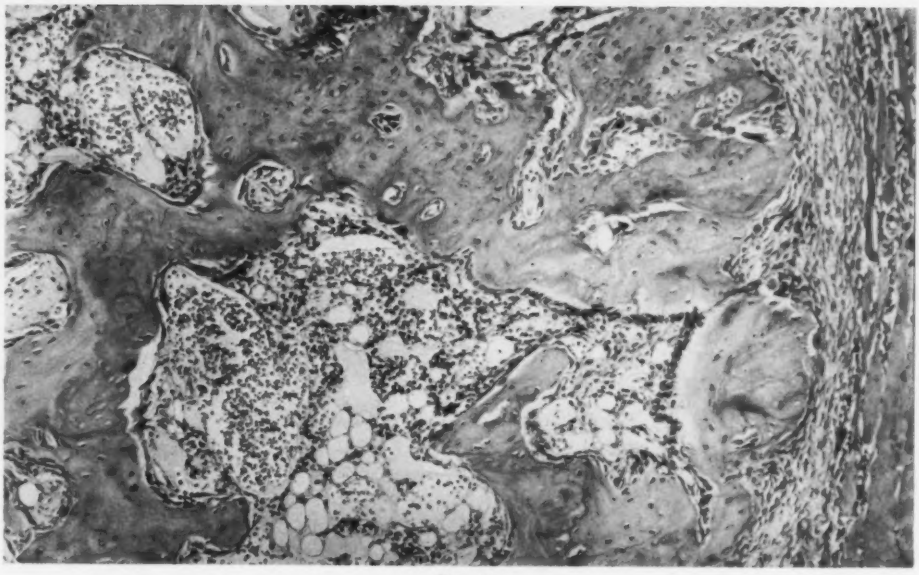


FIG. 6

Autograft, eighteen days (×105). The bone has now grown into an irregular sphere containing haemopoietic marrow. Note the active remodelling in progress as shown by the osteoblastic activity on some surfaces and osteoclastic activity on others.

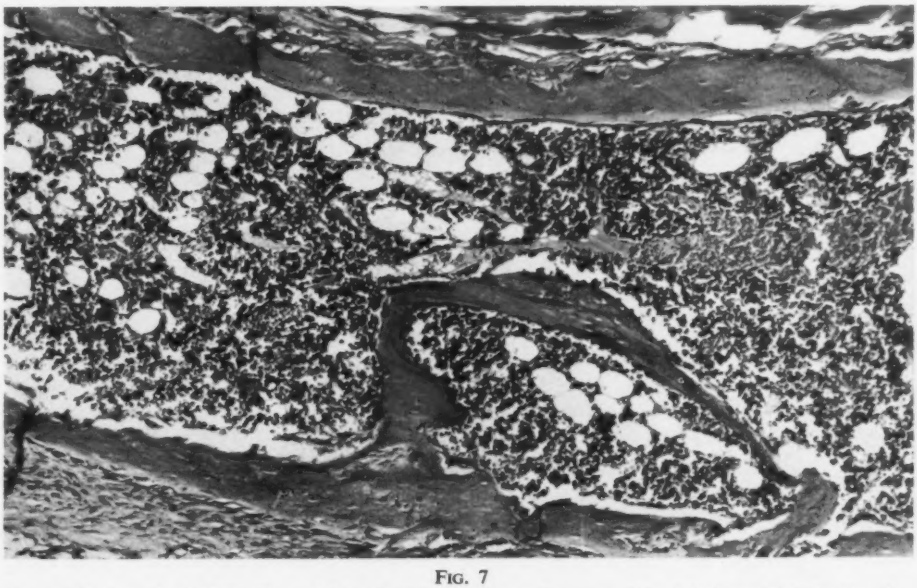


FIG. 7

Autograft, six weeks (×105). The ossicle has become complete and more regular. It is elongated in the direction of the adjacent muscle fibres.

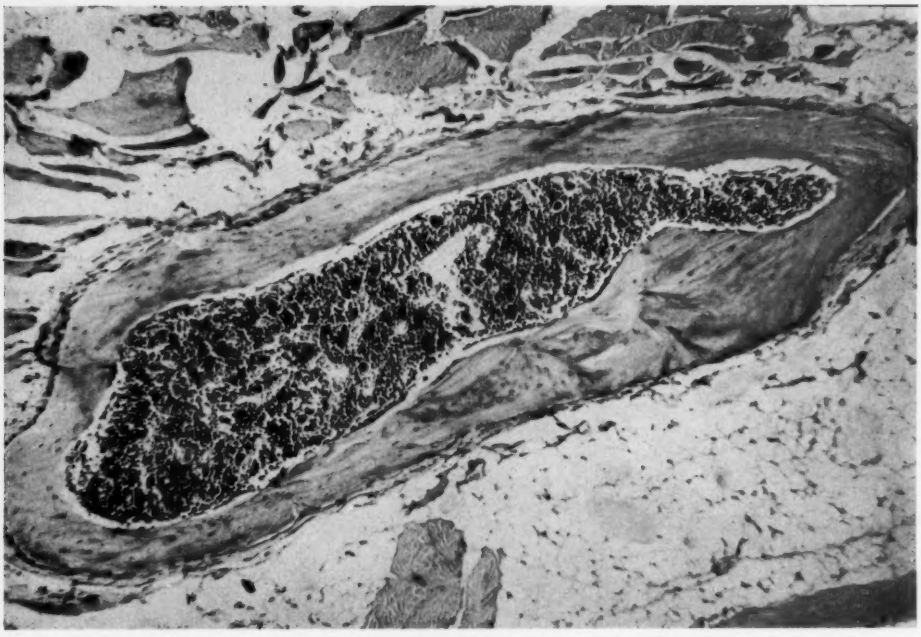


FIG. 8

Autograft, six months (×75). A late ossicle. A few small fragments of original graft are incorporated in the cortex of the ossicle. Note the complete absence of reaction in the surrounding tissue.

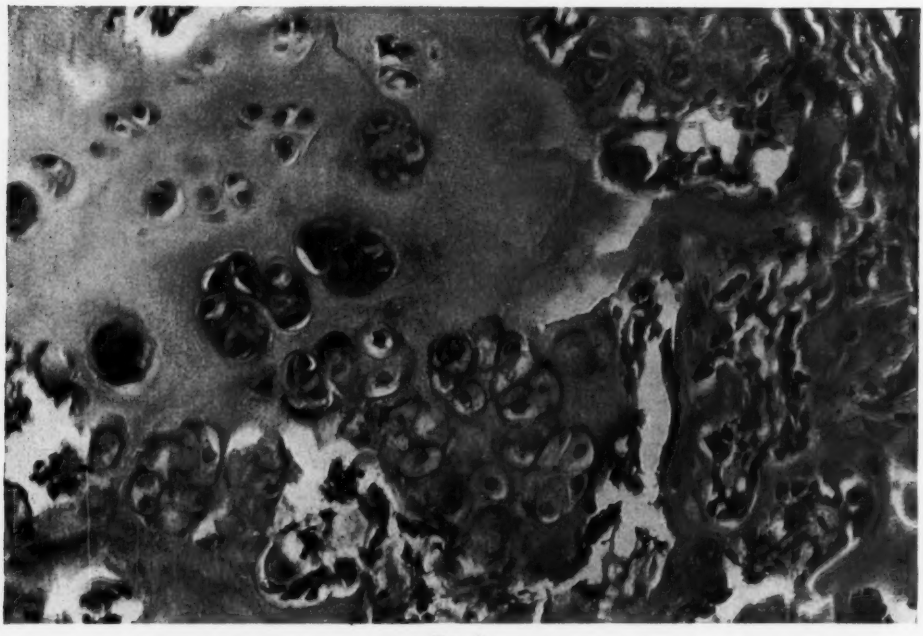


FIG. 9

Autograft, twelve days (×315). Showing area of cartilage formation at the graft site.

FIG. 10

Homograft, six days (×315). Showing new bone formation on surface of graft with osteoblast border in part. Most of the lacunae in the graft are empty.

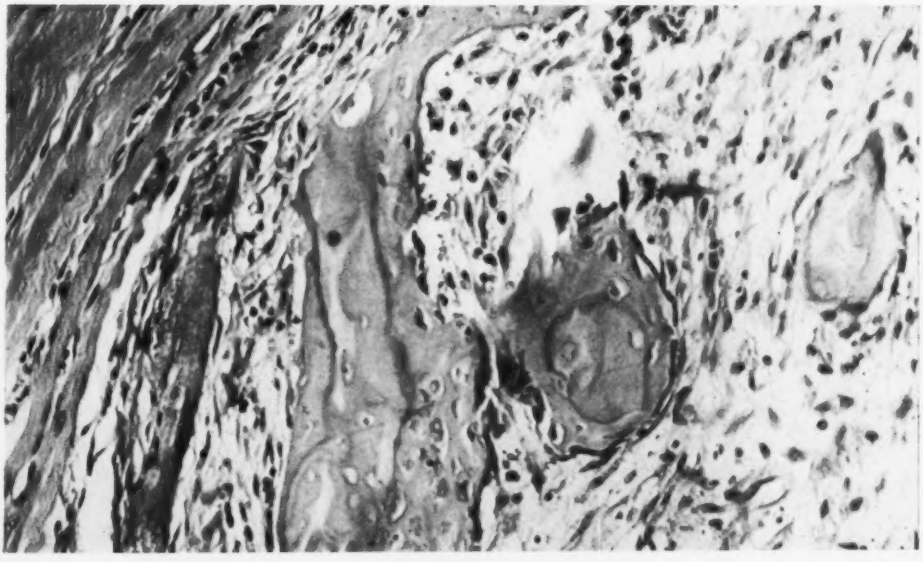


FIG. 11

Homograft, eight days (×290). The surface layer of osteoblasts on the new bone are flattened and more basophilic than normal, while the cells in the newly formed bone still appear normal. Contrast this with the autograft at ten days (Fig. 4) in which the surface osteoblasts retain their cuboidal structure.

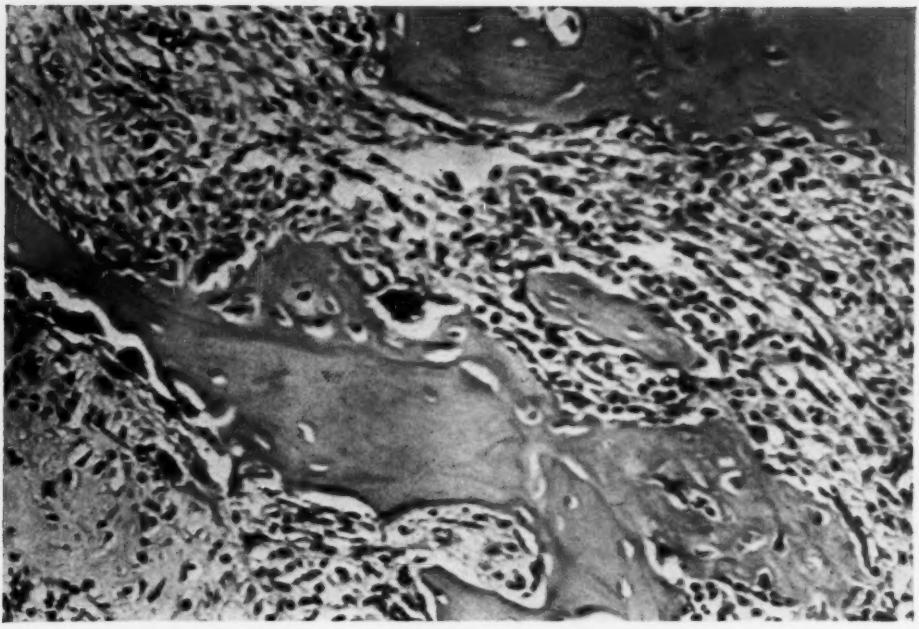


FIG. 12

Homograft, ten days (×315). Showing disappearance of surface osteoblasts and pyknosis of the cells in the new bone; osteoclastic resorption of the original graft and of the new bone is proceeding.

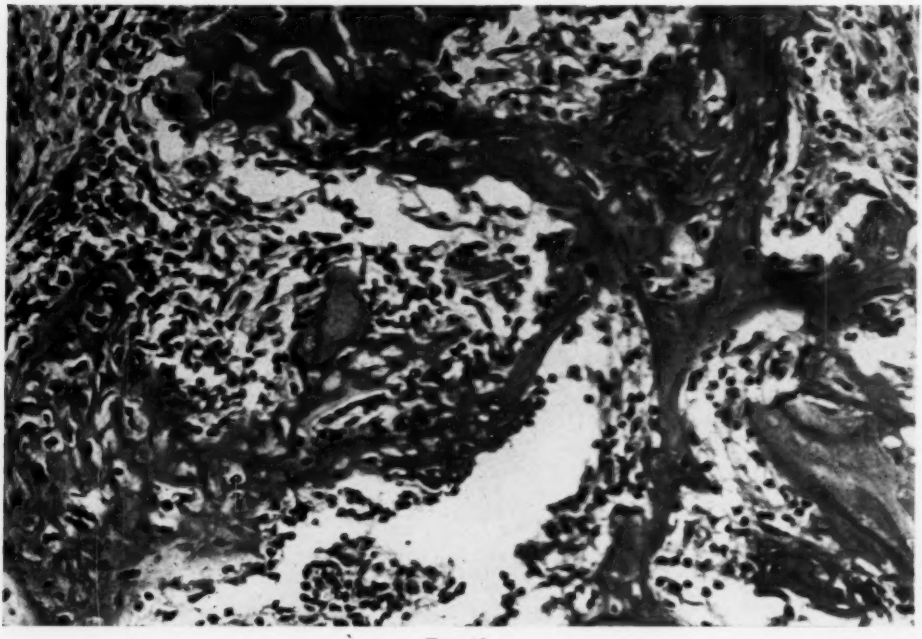


FIG. 13

Homograft, twelve days (×315). Some of the lacunae of the new bone are now empty while the remaining cells show degenerative changes. The inflammatory reaction to the graft is well shown.

FIG. 14

Homograft, sixteen days (×315). This photomicrograph illustrates the fact that when a large amount of new bone is formed in relation to a homograft many lacunae still contain bone cells at sixteen days.

FIG. 15

Homograft, four weeks (×315). The new bone which has formed in relation to the bone homograft, although dead and acellular, is still identifiable because of its characteristic open matrix.

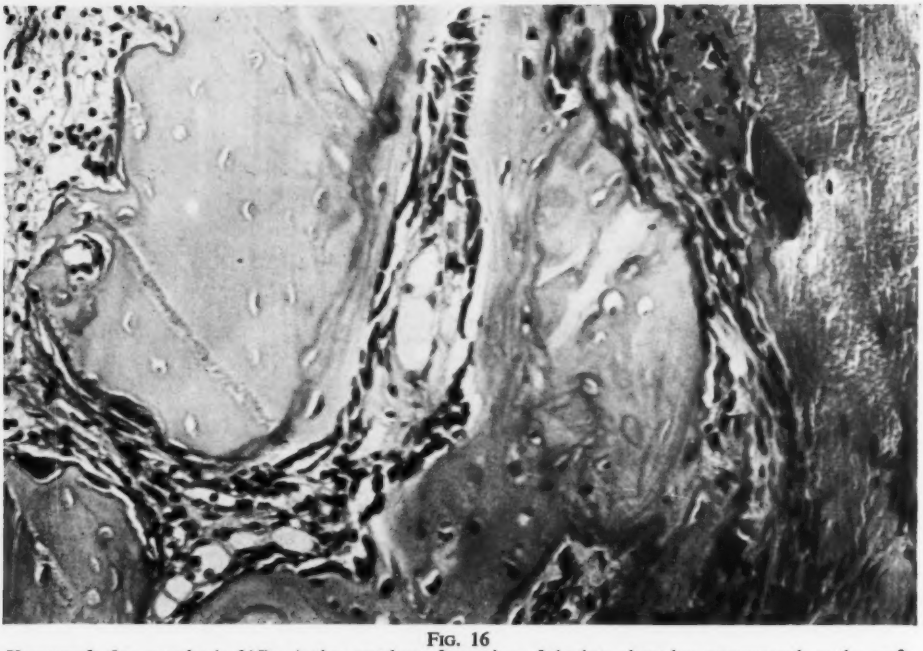


FIG. 16

Homograft, five months (×315). Active new bone formation of the late phase has commenced on the graft surface. The inflammatory reaction to the homograft is still present.

FIG. 17

Homograft, ten weeks (×315). Another example of the late phase of homograft new bone. Note that it remains closely applied to the surface of the original graft from which it is separated by a clear cement line. This new bone is lamellar in character. The inflammatory reaction is still present in the surrounding connective tissues.

formation to be identified even after the death of the cells concerned (Fig. 15). Resorption of this dead new bone proceeded rapidly, so that after four weeks it could be identified in only three of fourteen grafts.

TABLE II

A COMPARISON OF AUTOGRAFT NEW BONE AND EARLY AND LATE PHASES OF HOMOGRAFT NEW BONE

	Autograft	Homograft	
		Early phase	Late phase
Duration of growth and survival	Four days to at least six months	Four days to eighteen days	Four weeks to at least six months
Type of bone	Woven at first, becoming lamellar at fourteen days	Woven	Lamellar
Quantity	Profuse	Variable but usually scanty	Scanty
Incidence	100 per cent	78 per cent	30 per cent
Progress	Forms ossicle containing haemopoietic marrow	Resorbed rapidly after death	Forms plaque on surface of dead graft

A second phase of new bone formation sometimes occurred in homografts of four weeks and older. This phase consisted of slowly growing lamellar bone. It was never large in amount, and did not organise into an ossicle. It remained closely applied to the surface of the graft,

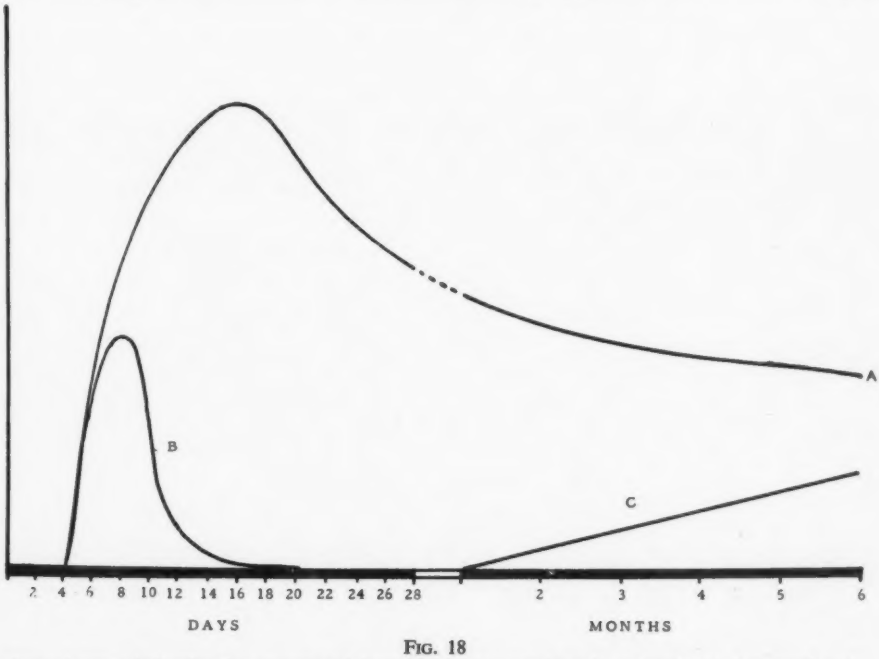


FIG. 18

General curves indicating the amount and duration of living new bone in autograft (A), homograft early phase (B) and homograft late phase (C).

a well marked cement line being present at the interface (Figs. 16 and 17). This type of new bone was seen in five of fourteen grafts of four weeks and older.

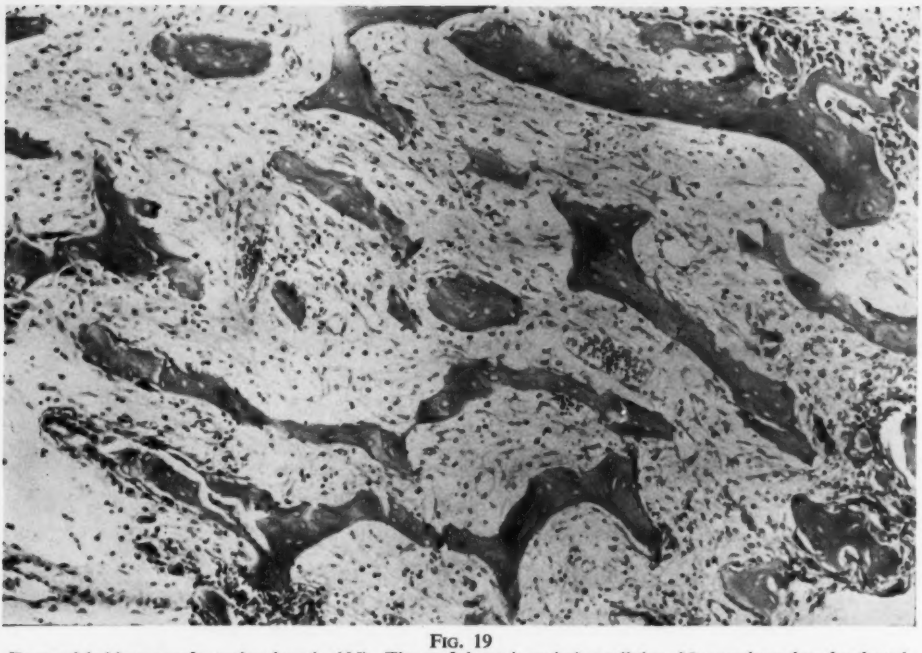


FIG. 19
Freeze-dried homograft, twelve days (×105). The graft bone is entirely acellular. No new bone has developed. The inflammatory reaction is less intense than that found in relation to the fresh homograft at this stage (*cf.* Fig. 13).

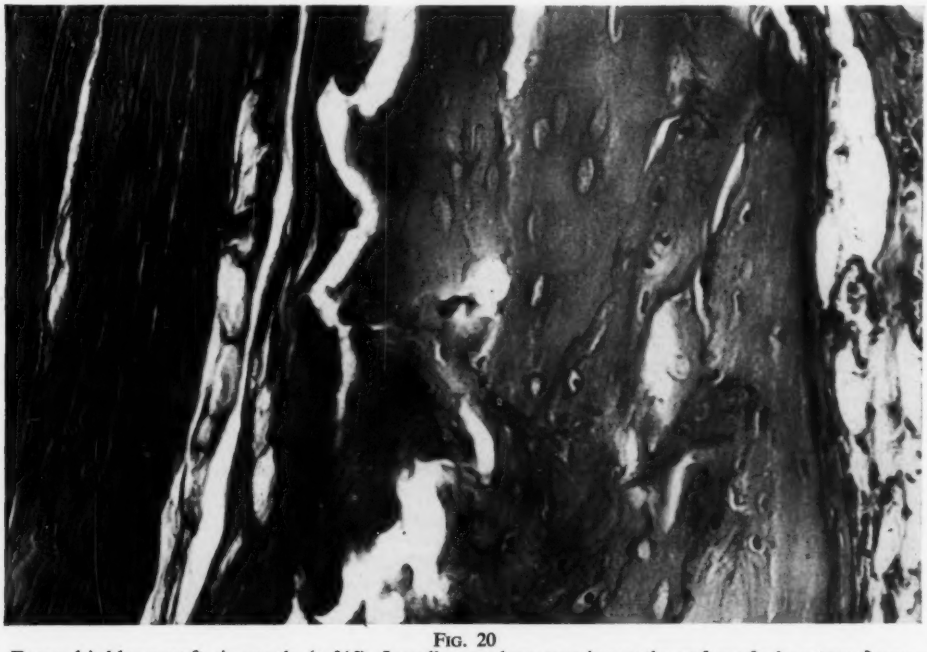


FIG. 20
Freeze-dried homograft, six months (×315). Lamellar new bone growing on the surface of a long term freeze-dried homograft.

Table II lists the characteristic features of the autograft new bone and the early and late phases of homograft new bone.

Figure 18 is a graphic impression of the time relationship of these three types of bone and their relative quantity.

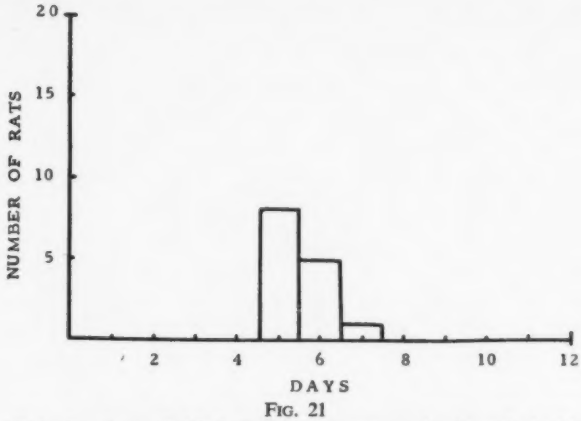


FIG. 21

Rejection times of skin homografts on rats previously grafted with fresh bone homografts from the same donor.

Osteoclasts were present from the fourth day, but resorption of the dead homograft proceeded more slowly than the dead autograft. The local response of the host tissues resembled that to the autograft until the eighth day. Thereafter there was an increase in fibrous tissue and a heavy infiltration with lymphocytes and varying numbers of plasma cells, eosinophils and histiocytes. This inflammatory reaction persisted until four to five months.

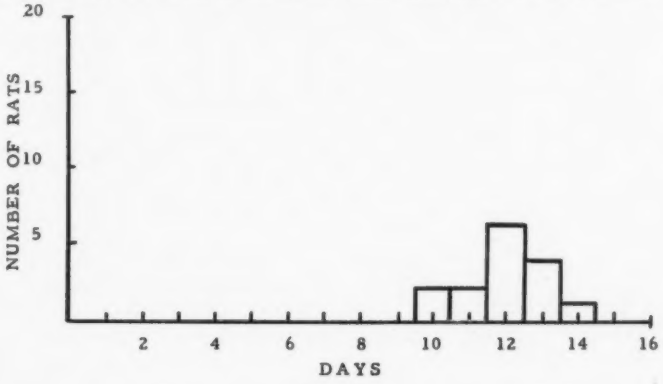


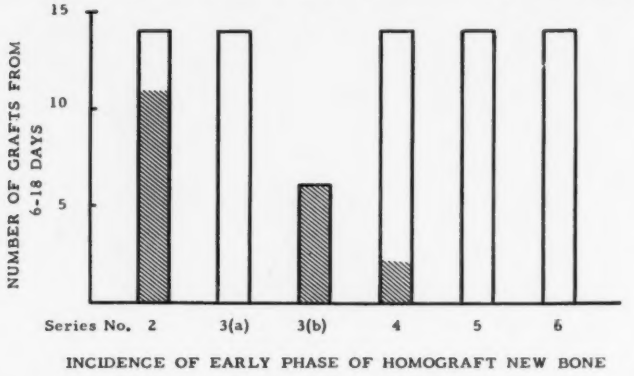
FIG. 22

Rejection times of skin homografts on rats previously grafted with freeze-dried bone homografts from the same donor.

Series 3a: Bone homograft three weeks after skin homograft from the same donor—In this series, as in the previous ones, only very few osteocytes survived transplantation. Neither the early nor the late phase of homograft new bone formation occurred. Resorption of the graft proceeded slowly, as in Series 2. The inflammatory reaction of the host tissues to the graft was similar to that in Series 2, but more intense in the early stages.

Series 3b: Bone homograft four months after skin homograft from the same donor—There were six animals in this series. The bone grafts were examined at thirteen days. In each case new bone characteristic of the early phase of homograft new bone was present. There was an inflammatory reaction to the grafts, as in Series 2.

Series 4: Bone homograft four weeks after bone homograft from the same donor—In this group there were two grafts to examine in each animal, the second grafts being of two days' to six months' duration whereas the first grafts were twenty-eight days older. Occasional osteocyte survival was observed in both. The second grafts gave two examples of early type new bone



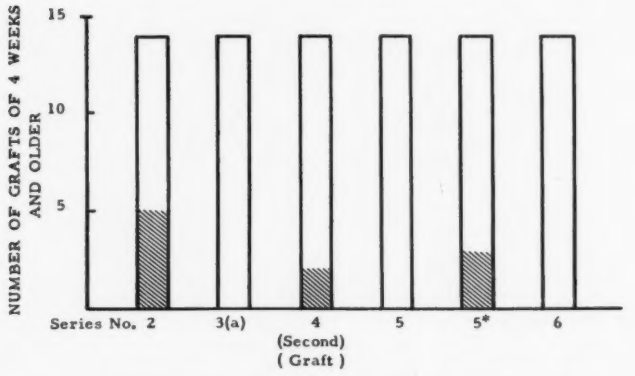


FIG. 23

Incidence of early phase and of late phase of homograft new bone.

in the fourteen grafts from six to eighteen days. Late phase new bone occurred in three of fourteen grafts of four weeks' duration and older. In the first grafts, the late phase new bone occurred in six of thirty-two grafts. The inflammatory reaction and slow rate of resorption of these grafts corresponded to Series 2.

Series 5: Freeze-dried bone homografts—No survival of osteocytes was observed in this series, all lacunae in the grafted bone being empty. No new bone occurred. Giant cells resembling osteoclasts were present from the sixth day and resorption proceeded slowly. The inflammatory reaction was less intense and later in onset than with the fresh homograft (Fig. 19). An additional number of longer-term grafts, of five to ten months' duration, was added to the

original series. Of these, three of fourteen showed small amounts of new bone with the characteristics of late phase homograft new bone (Fig. 20).

Series 6: Freeze-dried bone homograft four weeks after skin homograft from the same donor—This series behaved as Series 5. No survival of osteocytes was seen. No new bone developed by six months. Resorption associated with the presence of osteoclast-like giant cells progressed slowly. A mild inflammatory reaction occurred, as in Series 5.

Series 7: Skin homograft three weeks after fresh bone homograft from the same donor—There were fourteen animals in this series. The skin grafts had a mean survival time of 5·6 days (Fig. 21).

Series 8: Skin homograft three weeks after freeze-dried bone homograft from the same donor—There were fourteen rats in this series. The skin grafts had a mean survival time of 12·0 days (Fig. 22).

Figure 23 summarises the incidence of the early and late types of homograft new bone in the different series.

DISCUSSION

When these results are considered together certain patterns of behaviour of autograft and homograft bone emerge.

Survival of a few osteocytes was observed in all series in which fresh bone, whether autograft or homograft, was used, but not in freeze-dried bone grafts. Autograft gave rise to new bone which became organised into an ossicle with haemopoietic marrow. All bone, living or dead, which did not contribute to the ossicle was quickly removed. There was no inflammatory reaction to the autograft.

Fresh homograft was associated with two separate and distinct phases of new bone formation, early and late, the early phase terminating in death of the new bone by eighteen days. The incidence of both these phases was reduced by a previous homograft of bone from the same donor and abolished by a previous homograft of skin from the same donor. Freeze-drying the bone homograft prevented the development of the early phase, but the late phase developed in a few instances after a lapse of many months.

Resorption of the homografts was slower than that of the autografts. Bone homografts provoked a local inflammatory reaction which was more intense with the fresh than with the freeze-dried bone. The survival time of skin homografts was shortened by a previous homograft of fresh bone from the same donor, but was slightly prolonged by a previous freeze-dried bone homograft.

Some investigators have been reluctant to accept the theory of transplantation immunity because of the failure of many attempts to isolate antigens from tissue extracts and because of the failure to demonstrate the presence of antibody *in vitro* by the classical techniques such as cell agglutination and complement fixation. Billingham, Brent and Medawar (1956*a*) recently succeeded in isolating the antigens responsible for the homograft reaction in the nuclear fraction of spleen and kidney cells in mice and found it to be a desoxyribonuclear protein. The antigen was very unstable and was destroyed by drying from the frozen state, and by repeated freezing and thawing. They also described a second type of antigen present in the cytoplasm which is more stable and which can be demonstrated by orthodox serological techniques. This antigen does not evoke homograft response, but by some means not yet fully understood it delays the rejection of a subsequent homograft from the same donor—the " enhancement effect." Bonfiglio, Jeter and Smith (1955) succeeded in demonstrating antigens in extracts of rabbit bone. These may have been of the second category, for injections of this material reduced the reaction to subsequent bone homografts. Curtiss and Herndon (1956) were unable to show that bone possessed antigens of the blood groups in dogs.

There is much evidence that the antibody responsible for bone homograft rejection is bound to mobile cells of the host, and that actual contact of these cells with the cells of the graft is necessary before the reaction can take place. Transplantation immunity can be

transferred to another animal by implants of lymphatic tissue from an immune animal, but not by serum (Mitchison 1954). If the graft is excluded from the cells of the host by means of a diffusion chamber then it does not undergo rejection (Algire, Weaver and Prehn 1954). This may be the explanation for the continued survival of homografts of cartilage and cornea so long as they remain avascular, for in these tissues the cells are protected by a continuous mucopolysaccharide matrix (Loeb 1930, Peer 1954).

Against this background it is possible to draw a number of conclusions concerning the influence of transplantation immunity on bone homografts from the results of the experiments described above.

The observation that skin homografts after a previous bone homograft from the same donor (Series 7) undergo an early rejection, establishes that bone contains tissue antigens which evoke an immune response in the host. It is evidence, too, that bone and skin have antigens in common.

The existence of an immune response to homograft bone allows a clear understanding of the nature of the early new bone formation that occurs in relation to the autograft (Series 1) and the living homograft (Series 2). A latent period before the rejection of homografts of skin and other tissues exists because several days must elapse before the immune state of the host is developed sufficiently to bring about the death of the graft (Medawar 1954). During such a latent period, any surviving osteogenic cells of a bone homograft would have an opportunity of proliferating and forming bone. If, however, bone possesses tissue antigens that can evoke a reaction in the host, one would expect any new bone formed from homograft cells to have a limited period of survival. This is precisely the behaviour of new bone from homografts in the early phase, and is evidence that its origin is from grafted cells and not from the host tissues.

Danis (1956), who observed a similar phase of new bone formation with homografts of bone marrow in rabbits, came to the same conclusion; but Hutchison (1952), who was possibly the first to describe the early phase of homograft new bone, considered it to have arisen from host tissues. He did not, however, give his reasons for this opinion.

The failure of the early phase of homograft new bone to develop in Series 3a in which the animals had been immunised beforehand by a skin homograft is further evidence that this phase arises from cells of the graft, for once transplantation immunity has been established the animal has a heightened resistance to further grafts from the same donor.

The limited duration of transplantation immunity is shown by Series 3b in which each of the bone homografts carried out four months after a skin homograft from the same donor produced early new bone. This is in keeping with the duration of immunity against other tissues in rats recorded by Lehrfeld, Taylor and Converse (1955) and in mice by Billingham, Brent and Medawar (1954).

When the pre-immunising homograft was bone (Series 4) the suppression of the early phase of new bone growth was not so consistent as in Series 3a, for two of fourteen grafts showed new bone of this type. The reason for this may be that muscle is a less satisfactory site for the production of immunity than skin. It is known that levels of immunity may vary with the site of implantation (Medawar 1948; Billingham, Brent and Medawar 1956*b*; Billingham, Brent and Mitchison 1957).

Freeze-drying appears to inactivate histocompatibility antigens in bone homografts since subsequent skin grafts from the same donor did not undergo an early rejection but survived slightly longer than normal (Series 8). This prolongation of survival time, although small, was statistically significant* (Fig. 22). This may be an example of the " enhancement effect."

* Mean survival time of first set skin homografts—10·9 days. Standard error 0·13. Mean survival time of skin homografts following freeze-dried bone homografts—12·0 days. Standard error 0·29. Difference of mean of the two groups—1·1 days. Standard error of the difference 0·32. Application of the " t " test indicates that this difference is significant at the 0·01 level.

The modified antigenicity of freeze-dried bone homografts is reflected in the reduced inflammatory reaction at the host site. Pre-immunisation of the host did not increase this reaction (Series 6) as it does with some other killed tissue homografts (Darcy 1955).

The continued survival of a few osteocytes within the grafts of fresh homogenous bone despite the demonstrable existence of transplantation immunity is readily explained. Osteocytes are surrounded by bone matrix and are nourished by tissue fluid diffusing through small canaliculi: in an intact graft they do not come in contact with the host cells. Bone is in fact a natural example of Algire *et al.'s* (1954) diffusion chamber; like it, it excludes host cells and so protects its own cells from the immune reaction.

The bone cells of the early phase of homograft new bone, although often surviving longer than the surface osteoblasts, all die by the eighteenth day. Perhaps the immature matrix is an incomplete barrier to the host cells, or perhaps there is a local interruption of blood supply such as has been so well described by Taylor and Lehrfeld (1953) in the case of the rejecting skin homograft.

The histogenesis of the late phase of homograft new bone remains unsolved. There are two possible sources: from the graft itself or from the adjacent connective tissue of the host which has undergone metaplasia into bone-forming tissue. The fact that transplantation immunity has been established against the graft does not eliminate the possiblity that graft cells may be responsible, for it has been suggested that homografted tissues which are kept alive beyond a certain critical period are no longer susceptible to the immune response (Woodruff 1952). One could argue that the living osteocytes which were demonstrable in the fresh homografts might become liberated during the process of resorption and resume osteogenic function. Evidence in favour of the metaplastic origin of this bone is provided by the fact that it developed in relation to several of the freeze-dried bone grafts (Series 5). Freeze-drying kills mammalian skin (Billingham and Medawar 1952) and mature bone (Ray *et al.* 1952, Pate 1954): in the present experiments there was no histological evidence of cell survival in any of the freeze-dried bone grafts used. Whether bone can in fact induce metaplastic bone formation in adjacent connective tissue is the subject of much discussion at the present time. There are many reports of new bone developing around grafts of dead bone in soft tissues (Wilson 1951, Axhausen 1953, Urist and McLean 1952, Curtiss and Wilson 1953, Maatz 1955, De Bruyn and Kabisch 1955) but others have failed to confirm this (Ray *et al.* 1952, Ham and Gordon 1952, Keith 1934, Campbell *et al.* 1953, Danis 1956). The experiments recorded in this paper suggest that dead bone can induce metaplastic bone formation in non-skeletal connective tissue, but that this occurs infrequently and only after a long period.

From this study it is possible to draw the following conclusions which have a bearing on clinical bone grafting.

1. Bone homografts, whether living or dead, are not able to make a significant contribution of living bone tissue (except in a few special instances such as a graft to an identical twin).

2. There is then no advantage of living homograft over preserved material. Indeed, preserved bone may be preferable in view of its altered antigenicity.

3. The lack of a supply of living cells in the homograft, together with its slower resorption, could account for the differences of behaviour that have been observed clinically between autografts and homografts.

SUMMARY

1. Fresh bone autografts to a muscle bed in the rat gave rise to vigorous new bone formation from about the fourth day. The graft took the form of a hollow ossicle with central bone marrow at eighteen days: it became progressively more regular in outline and was still present at six months.

2. Fresh bone homografts produced two separate phases of new bone formation—early and late. In the early phase non-lamellar woven bone appeared at about the fourth day, continued

to grow until eight days, and subsequently died. It arose from osteogenic cells of the homograft. In the late phase, which developed in relation to a few grafts after four weeks, the new bone was lamellar in character, and remained closely applied to the graft surface. Evidence is presented that this bone arose by metaplasia of the host connective tissues at the graft site. There was a local inflammatory response to the bone homograft.

3. Both phases of homograft new bone formation were abolished if the animal was prepared by a skin homograft from the same donor four weeks before, but not if four months elapsed between the two grafting procedures.

4. Freeze-dried bone homografts did not give rise to the early phase of homograft new bone but produced a few examples of the late phase after five months. The inflammatory response was less intense with freeze-dried homografts than with fresh homografts.

5. Skin homografts three weeks after fresh bone homografts from the same donor underwent an early rejection at five to six days.

6. Skin homografts three weeks after freeze-dried bone homografts from the same donor had a mean survival time of twelve days, which was significantly longer than the mean survival time of 10·9 days in normal rats.

I am most grateful to Mr H. J. Seddon for the opportunity of doing this work, and to Dr H. A. Sissons for encouragement and advice during the period I spent in his department. My thanks are due also to Professor P. B. Medawar for many helpful suggestions, and to the technical staff of the Department of Morbid Anatomy of the Institute of Orthopaedics for their invaluable assistance.

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BILATERAL CORACO-CLAVICULAR ARTICULATIONS IN THE AUSTRALIAN ABORIGINAL

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During the course of a metrical and non-metrical study of the clavicle of the Australian aboriginal one pair of bones out of the 292 clavicles examined showed features of the conoid tuberosity well beyond the normal range of variation. These features were reflected also in the corresponding coracoid processes of the scapulae and indicated that, in life, these bones had been in articulation.

The skeleton was that of a male and the bones were in good condition.

THE CLAVICLES

The atypical features were present in both clavicles with only slight differences in the dimensions of the articular facets on each side (Table I).

TABLE I

DIMENSIONS OF THE ARTICULAR FACETS ON THE CLAVICLES

	Measurement (*millimetres*)	
	Right	Left
Long axis (medial to lateral)	12	15
Short axis (antero-posterior)	6	9

The under surface of the bone presented a well marked subclavian groove, the posterior lip of which was accentuated over its lateral third. The conoid tuberosity was clearly separable

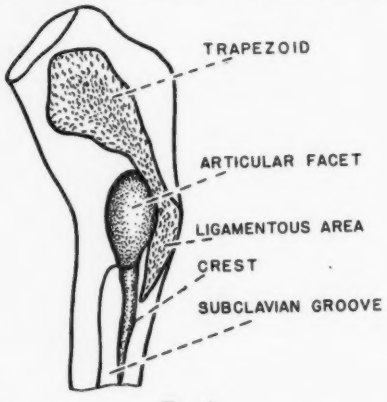

FIG. 1

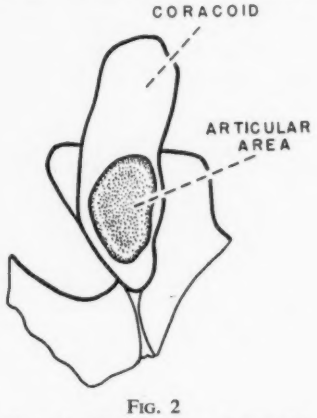

FIG. 2

Figure 1—Lateral end of left clavicle from below. Figure 2—Upper surface of coracoid process of left scapula.

into two parts. The posterior part was roughened and faced obliquely backwards and downwards: traced laterally this part was continuous with the postero-medial limit of the marking for the

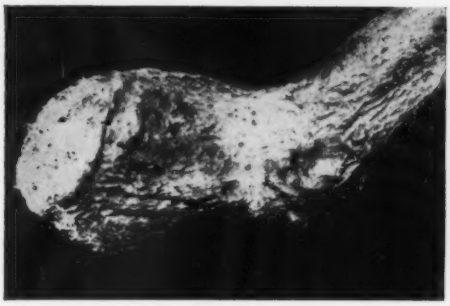

FIG. 3

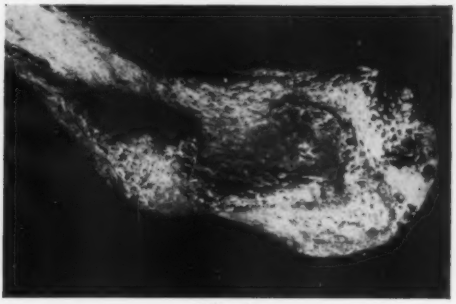

FIG. 4

Right and left clavicles showing the articular facet on the conoid tuberosity of each.

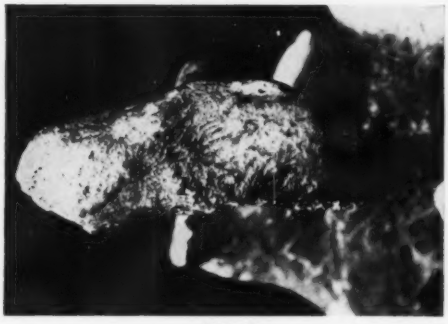

FIG. 5

FIG. 6

Right and left coracoid processes showing the articular area on each.

trapezoid liagment. The anterior part of the tuberosity was discrete and presented a smooth surface facing forwards and downwards. It was slightly convex from before backwards and more so from side to side (Figs. 1, 3 and 4).

THE SCAPULAE

Each coracoid process was of normal general shape, but showed a definite reniform depression on the upper surface near the medial end (Figs. 2, 5 and 6). When the clavicle and scapula were articulated, this depression was immediately opposed to the smooth facet on the conoid tuberosity. The depression was smoother than the rest of the upper surface of the coracoid, but not so smooth as the corresponding conoid tuberosities. The differences between right and left were again in size only, and slight (Table II).

TABLE II

DIMENSIONS OF THE ARTICULAR FACETS ON THE CORACOID PROCESSES

	Measurement (*millimetres*)	
	Right	Left
Long axis (in axis of coracoid) . . .	18	19
Short axis (at right angles to axis of coracoid)	13	13

On casual observation the depressions on the upper surface of the coracoid processes might easily be overlooked, unlike those on the clavicles.

THE ARTICULATED BONES

When the bones were articulated the smooth area of the conoid was facing towards the corresponding area of the coracoid process, but separated from it by a few millimetres—a distance that was not great enough to preclude a direct articulation during life.

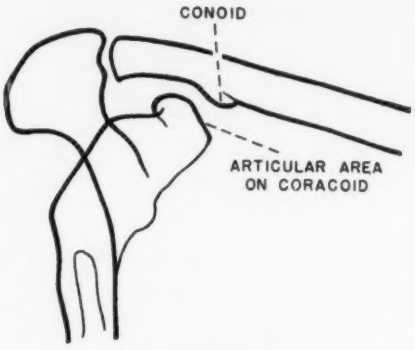

FIG. 7
Tracing of a radiograph of the right clavicle and scapula.

The articulated bones were radiographed and a tracing is shown in Figure 7. It will be noticed that the conoid does not appear to be unduly large, and the appearance might easily pass as within normal limits. However, the features of the dried bone certainly indicate the presence of an articulation. Perhaps in this observation lies the answer to the difference of opinion that exists about the rarity of this abnormal joint.

DISCUSSION

A survey of the literature reveals conflicting evidence on the occurrence of a coraco-clavicular joint in man.

Two aspects of the problem require consideration. The first concerns the frequency of the condition and the second the nature of the joint. According to Hall (1950), only fifty-four cases have been reported in the world literature, most of these having been discovered

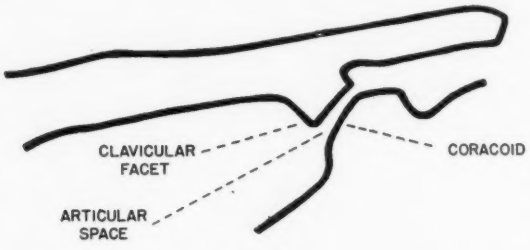

FIG. 8
Tracing of coraco-clavicular articulation illustrated by Wertheimer (1948).

accidentally either at necropsy or during radiological examination for some other reason. Other authors have also emphasised the rarity of the condition, and Wertheimer (1948) analysed the recorded cases. Other authorities, however, have stated or implied that the condition is not rare (Nutter 1941, Poirier and Charpy 1899, Lane 1888).

Before the advent of radiography cases reported were those encountered at necropsy or during anatomical dissections. After the introduction of radiography most of the reported

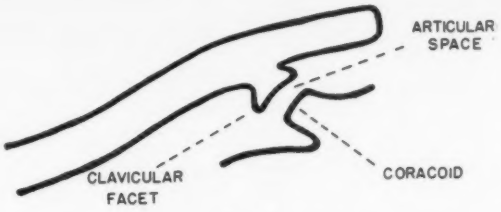

FIG. 9
Tracings of coraco-clavicular articulation illustrated by Nutter (1941) with a well developed conoid facet.

examples have been either noticed accidentally or have been discovered only when a detailed study of the shoulder has been made for some painful condition, the cause of which was not

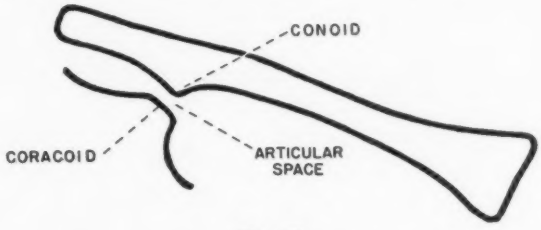

FIG. 10
Another coraco-clavicular articulation illustrated by Nutter (*loc. cit.*), but with a small conoid facet.

immediately demonstrable (Hall 1950, Gradoyevitch 1939, Wertheimer 1948). Nutter, on the other hand, approached the problem in a more analytical fashion and was presumably aware

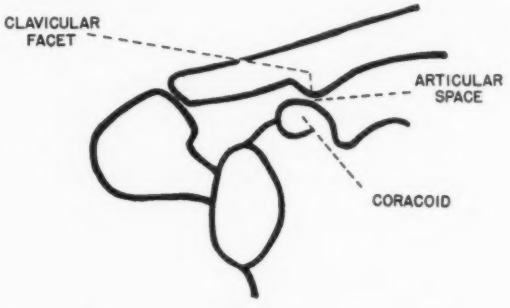

FIG. 11
Tracing of a coraco-clavicular articulation illustrated by Miessen. The conoid facet is small.

of the possibility of this condition when he examined his films. This accounts for his report of a much higher incidence than other workers.

The examples illustrated by Wertheimer (Fig. 8) and Hall had a very large conoid tuberosity with a well marked flattened facet at its apex. In such a case the conoid tuberosity

is obviously unusual and the diagnosis of the atypical joint is well established. A similar case was illustrated by Nutter (Fig. 9) but, in addition, he also illustrated a joint that was not so obvious (Fig. 10). The latter case is very like the ones reported here. It is also interesting that reports of actual dissections (Gowland 1915, Miessen 1937, Schlyvitch 1937) contain descriptions of the bones which are like the cases now described (Fig. 11). One of the three cases reported by Meyer (1915) is also similar, but his other cases were associated with excessive bone formation which would make radiographic diagnosis obvious.

It seems clear, then, that if the joint is present but the bony surfaces are not exaggerated, its presence may easily be overlooked. In these conditions one must agree with Nutter that "the anatomical and physiological significance of these joints is only academic. However, inasmuch as they are true joints, it can be presumed that they are not exempt from any of the various pathological conditions which affect any other joint." It is possible, too, that sometimes this joint, especially when it is pathological, may interfere with the mechanics of the shoulder girdle. Whether one can agree with Frassetto (1921), who regarded its presence as predisposing to fractures of the surgical neck of the humerus, is doubtful.

The possible existence of this abnormal joint should be borne in mind especially in cases of shoulder pain, or limitation of shoulder movement, in which the cause is obscure.

SUMMARY

1. A pair of clavicles and the corresponding scapulae were found to possess definite articular facets indicating the presence, in life, of a coraco-clavicular joint.
2. The bones are described and illustrated.
3. These cases are compared with others reported in the literature.

I would like to express my thanks to Mr George Murray Black, who collected the specimens used in this survey, and to Professor S. Sunderland for his advice in the preparation of this paper.

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BLOOD SUPPLY OF GROWING RABBIT'S TIBIA

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Until recently our knowledge of the blood supply of the long bones was mainly based on the work of Lexer and his school (Lexer, Kuliga and Turk 1904), who, considering the technical limitations of the time, obtained excellent illustrations of most of the main vessels. In 1934 Belou published his monumental anatomical atlas of human vasculature with a section on osteology. But, like the work of Lexer, Belou's lacks information on the vessels once either their size impeded the penetration of the thick injection mass, or, in the better injected specimens, the wide diffusion of the injected material blurred the limits of the individual vessels. Thus confusion remained as to the relative participation of each of the systems of vessels in the supply of the bone tissue. To obviate the drawbacks of method authors in general relied on suppositions supported by drawings. Exceptionally, indirect methods of stimulating the vascular supply of bone were used, as by Johnson (1927).

Many of the recent studies do not escape from these serious limitations, as some rely solely on results of animal experiments, which seek to suppress one or other source of blood, without giving data on the vessels themselves. Others report the shape, size and arrangement of the vessels in bone by drawings (Marneffe 1951), or by drawings supported by photographs showing the gross anatomy (Brookes and Harrison 1957).

The introduction of new techniques and materials has facilitated and improved the process of intravascular injection, so that accurate photographic reproductions of the vessels can be obtained.

During the past few years investigations of problems of blood supply have resulted in the accumulation at this Centre of considerable information on the blood supply of the human skeleton and of some animals. Particularly rich information has been gathered on the rabbit's tibia, the material available having been put together in order to act as a " normal " for the purpose of comparison during experimental work. The aim of this report is to place at the disposal of other investigators the general pattern of the vasculature of the rabbit's tibia.

MATERIALS AND METHODS

The rabbits were all of mixed breed and of various ages, but mainly before the closure of the epiphysis. Some five hundred bones have been examined.

The techniques used to demonstrate the blood vessels were those previously described (Trueta, Barclay, Daniel, Franklin and Pritchard 1947; Trueta and Harrison 1953), the injection being performed in all cases under general anaesthesia, with the canula fixed into the distal part of the aorta. No attempt was made to estimate the injection pressure used, and nearly always the injection was performed with an ordinary 10 cubic centimetre syringe.

The injection materials were a 10 per cent barium sulphate suspension (Micropaque), colloidal silver iodide 10 per cent, and Berlin blue 2 and 4 per cent—usually alone, but sometimes the materials were mixed. The injected specimens were examined by radiography and in some cases by microradiography. The general pattern of the vessels was also studied by the Spalteholz technique in whole bones and in sections of the bones. The smaller vessels were examined under the microscope using histological preparations with the tissue embedded in 20 per cent low viscosity nitrocellulose and cut in thin sections of about 15μ and thick sections of about 400μ, the thin sections being examined stained with haematoxylin and eosin and the thick sections examined unstained under low power microscopy.

OBSERVATIONS

It is well known that the blood supply to a long bone is provided from three sources: the nutrient artery, the epiphysial arteries and the periosteal arteries. The distribution of the vessels themselves is less well known, and it is therefore the purpose of this paper to describe it.

The venous drainage of bone shows marked differences from the usual systemic pattern, for in bone the veins, which are very numerous and thin walled, seldom accompany the arteries, but have a distinct and peculiar pattern of their own.

The picture is further complicated in the case of the rabbit's tibia by the fact that the lower half of the bone is of composite construction, the lateral portion being phylogenetically the lower end of the fibula; so some duplication of the normal vascular arrangement is produced.

FIG. 1

FIG. 2

Figure 1—Dissection of rabbit's tibia showing injected nutrient and accessory nutrient arteries. Figure 2—Spalteholz preparation showing division of nutrient artery into ascending and descending branches.

THE NUTRIENT ARTERIES

In the rabbit the anterior tibial artery enters the leg from the popliteal fossa, lying close to the upper tibio-fibular joint (Fig. 1). As the vessel passes downwards, lying between the tibia and fibula, it gives off two branches which might be called the nutrient arteries of the tibia. The larger and more constant of these we have called the nutrient artery, and the smaller, the accessory nutrient artery. At its beginning the nutrient artery lies close to the tibia on the lateral side, but as it reaches the middle of the shaft it enters a groove and then penetrates the cortex at an oblique angle through the nutrient foramen. Almost as soon as it has penetrated the cortex it divides into ascending and descending branches.

FIG. 3

Antero-posterior and lateral microradiographs of upper two-thirds of tibia. The upper part shows division of the ascending branch of the nutrient artery. Lower down, parts of the descending branch and the accessory nutrient artery and emissary vein are just in view.

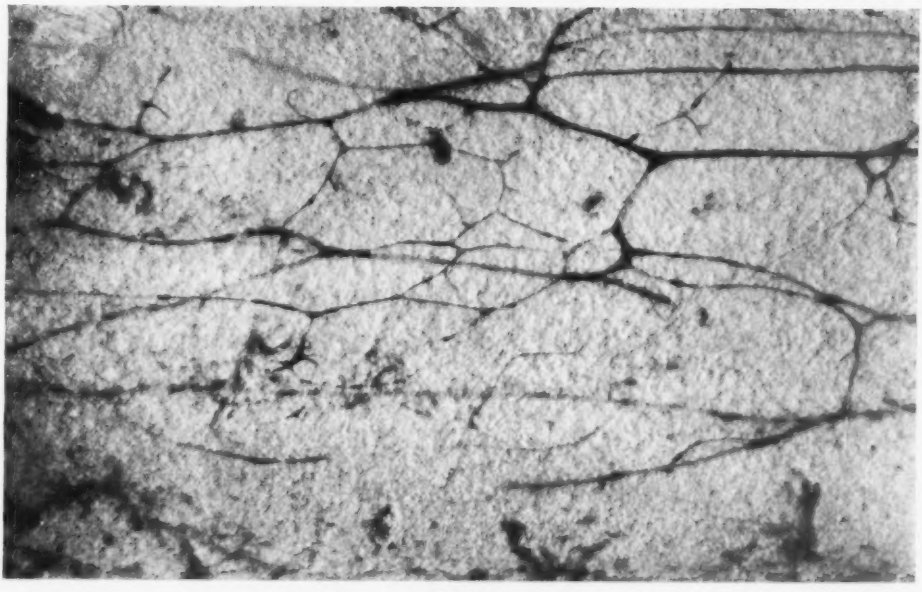

FIG. 4

Photomicrograph of part of marrow cavity showing anastomoses between branches of nutrient arteries.

The ascending branch—The ascending branch of the nutrient artery, which is larger than the descending, at first passes downwards and medially and then turns abruptly upwards forming a single or double loop (Fig. 2). At the beginning of the artery, while it is still pointing distally, a large number of fine, straight branches are given off, which cross the medullary cavity to pierce the cortex. The artery now divides into three or more ascending branches, which pass upwards towards the metaphysis, running in an almost straight line (surrounded on all sides by the sinusoids and cells of the marrow), but gradually spreading apart from each other as they go (Fig. 3). The three arteries at first lie near the back of the medullary cavity, but one

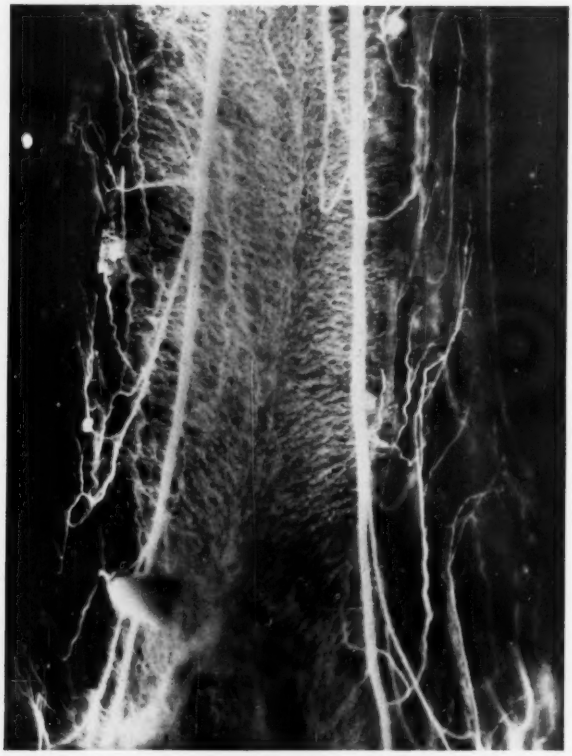

FIG. 5

Microradiograph of part of lower half of tibia. Descending branch of nutrient artery on the left side, accessory nutrient artery on the right side. The vessels show as straight white lines against the background of " herring-bone " sinusoids.

inclines forwards and gives off a number of small branches, which pass towards the anterior cortex (Fig. 3). The other two give branches to the posterior cortex. Each cortical branch at first runs a straight course approximately parallel to the main vessel, and then turns backwards or forwards to its destination, usually in the cortex, but sometimes in the marrow, where it links up with similar vessels to form a network of open square form like chicken-netting (Fig. 4). In the region of the metaphysis, where the shaft widens to form the funnel, each artery begins to break into branches: those vessels which then lie nearest to the cortex follow the wall outwards as it expands, giving off vertical branches at intervals, to supply the more peripheral portions of the plate, while the more central vessels continue an unwavering course

to the middle region of the cartilage. Close to the epiphysial plate the branches divide and subdivide into numerous small, straight branches, which finally terminate as the capillary loops of the metaphysial side of the upper epiphysial plate of the tibia.

The descending branch—The descending branch is usually a single vessel which passes down the medullary cavity towards the lower tibial metaphysis. At first it lies lateral to the numerous small, straight branches of the ascending artery, which in this situation form an oblique fan-like arrangement as they pass downwards across the medulla to reach the inner wall of the cortex. The descending artery continues distally, lying close to the posterior cortical wall, dividing into two or three branches in the lowest third of the bone. These run almost parallel to each other. Small branches which are given off from these vessels pierce the bony cortex. These have a characteristic form, running for a distance parallel with the main vessel and then curving back on themselves before passing into the cortex. As the three main vessels pass towards the metaphysis in an almost straight line through the medullary cavity, they are surrounded by a dense network of sinusoids (Fig. 5). Parts of the sinusoids lie parallel to the vessels themselves, forming a separate kind of sheath to the artery. Close to the epiphysial plate each artery breaks up into a number of major branches. These in turn each end by dividing again several times and in this last division there is considerable anastomosis between branches. Finally, each branch terminates as a long thin straight vessel, which ends by forming a capillary loop on the metaphysial side of the lower epiphysial plate.

It is important to note that as the lower end of the rabbit's tibia is a composite bone, it is formed in two portions (Fig. 6), and each has its separate blood supply (Fig. 7), the medial half from the descending branch just described and the lateral half from the accessory nutrient artery. This duplication of vessels is a feature also found in the veins in this situation.

THE ACCESSORY NUTRIENT ARTERY

The accessory nutrient artery, which is smaller than the nutrient artery and somewhat less constant, being occasionally replaced by a branch from the descending artery, arises from the anterior tibial artery at a slightly lower level than the nutrient artery (Fig. 1). It passes downwards and medially to lie between the tibia and fibula at the inferior tibio-fibular junction. There the artery pierces the lateral cortex of the tibia and passes downwards in the medullary cavity on the lateral side of the bone like the descending branches of the nutrient artery. It is usually a single straight vessel, and ends by dividing and subdividing into a number of fine branches, which end as the subchondral capillary loops of the " fibular " or lateral side of the metaphysis.

THE EPIPHYSIAL ARTERIES

The upper epiphysis—The upper tibial epiphysis consists of two parts: the larger forms the tibial plateau, the smaller the anterior tongue-like projection of the tibial tuberosity (Fig. 8). The main epiphysis receives its blood supply through its proximal face in those parts of the bone that are non-articular. As is usual in an epiphysis, there are several vessels concerned. These enter the bone anteriorly close to the mid-line as branches of the anastomosis behind the quadriceps tendon (Figs. 3, 9 and 10). Usually three vessels are present, which pass backwards and downwards in the substance of the epiphysis, dividing into continuous arcades of branches which run centrifugally towards the subchondral region. On that surface of the epiphysis which forms one boundary of the epiphysial plate, the branches are larger and closer together. The typical arrangement of the terminal branches of an epiphysial artery is shown in Figure 11. The vessel passes through the marrow to reach the terminal bone plate, which it pierces at a right angle accompanied by one or more veins, and in the subchondral region it turns parallel to the cartilage plate and divides into a number of short branches, which arise at right angles to the parent trunk. These short thick branches end by dividing into two or three capillary loops.

FIG. 6

Photomicrograph of longitudinal section of the lower end of a three-week-old rabbit's tibia, showing the bipartite structure. (Stained.)

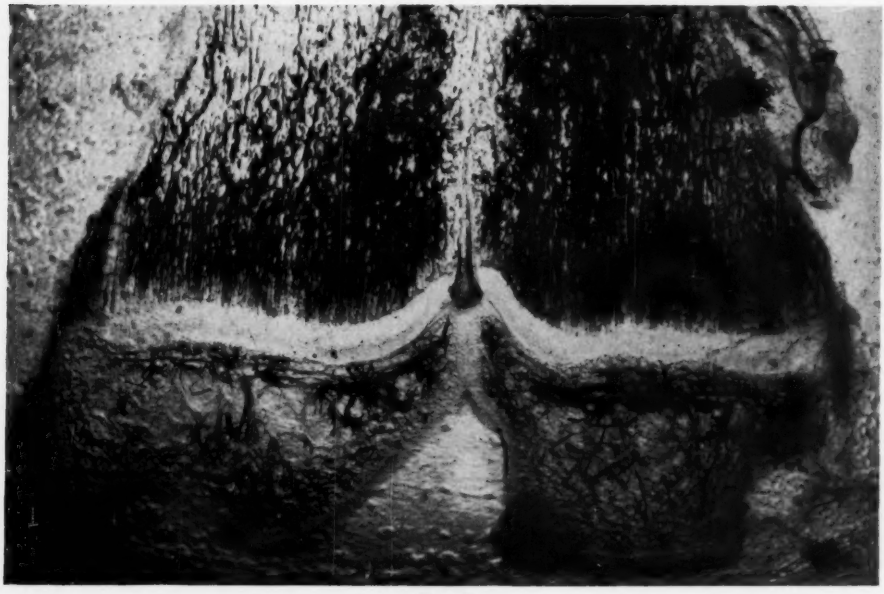

FIG. 7

Spalteholz preparation. Thick longitudinal section of lower end of bipartite tibia. (Unstained.) Blood vessels appear black.

FIG. 8

Spalteholz preparation. Thick sagittal section of upper end of tibia. (Unstained.) The vessels are injected with Berlin blue and appear black. The two parts of the epiphysis are divided from each other and the metaphysis by the clear zone of the cartilage plate.

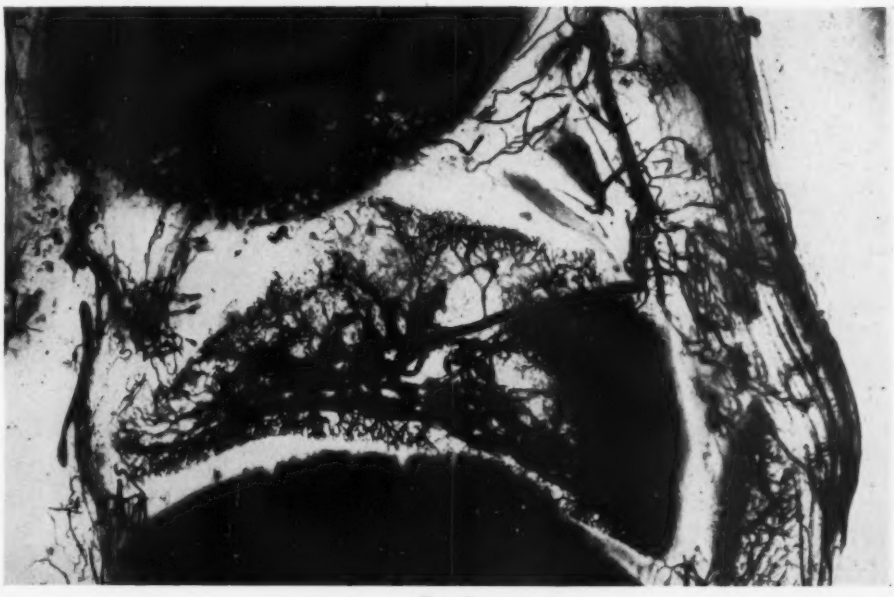

FIG. 9

Spalteholz preparation. Thick section injected with Berlin blue. (Unstained.) Lateral view of upper tibial epiphysis showing large nutrient artery entering epiphysis.

FIG. 10
Microradiograph of upper tibial epiphysis from above. Injected vessels appear black.

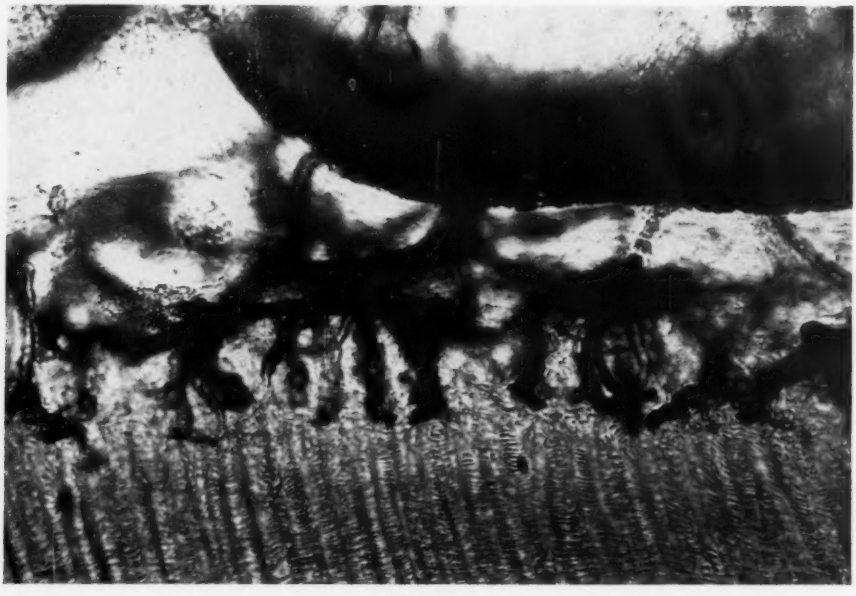

FIG. 11
Photomicrograph of thick unstained section from upper end of tibia to show terminal branches of epiphysial arteries and subchondral loops.

The anterior tongue-like portion of the upper tibial epiphysis, which later forms the tibial tuberosity, also receives its arterial supply from the anastomosis behind the quadriceps tendon, a number of small branches passing down behind the tendon into the epiphysis. There is also a small supply which enters its superficial surface from the longitudinal periosteal vessels. It appears also that a few of the long straight branches in the lower insertion of the tendon also connect with this part of the epiphysis.

The lower epiphysis—The lower tibial epiphysis is in two parts, a medial (or tibial) part and a lateral (or fibular) part. Both receive their nutrient arteries from the anastomosis about the ankle. This anastomosis is formed by the six or seven longitudinal periosteal arteries, which give branches to form an anastomosis at first proximal to the epiphysial plate, and secondly around the joint line itself. The vessels from this source enter the epiphyses from the superficial surface of the bone at the medial and lateral sides respectively. The larger nutrient arteries are usually two or three in number. The medial epiphysis has the most constant arrangement, the principal vessel entering from the anterior and inferior surface of the epiphysis, close to the mid-line, where there is a sort of interval (Figs. 12 and 13) between the two epiphyses and where, in fact, in early life the rabbit has a bifurcation of the whole lower end of the bone, epiphysis, plate and metaphysis, so that vessels may pass from below upwards between the two morphological halves of the bone. The medial epiphysis has other branches besides the anterior one and may even have a posterior branch. The anterior and lateral arteries together with the other twigs join to form a series of vessels running centrifugally and then dividing into arcades, as in the other epiphyses, and finally terminating as the epiphysial subchondral loops. The venous side of the loop is drained into the marrow sinusoids; the veins at first accompanying the arteries back through the cortical layer of the epiphysis before entering the sinusoidal system proper.

The lateral part of the lower tibial epiphysis has a much more variable arrangement of nutrient arteries, but on the whole they tend to enter the bone from the lateral and posterior aspect, but there is quite often a small anterior branch also. The usual distribution occurs inside the bone: the branches of the various arteries form a series of centrifugally running vessels, which form anastomosing arcades before piercing the bony shell of the epiphysis to reach the subchondral region, where they terminate as the subchondral loops.

THE EPIPHYSIAL PLATE

The histological appearance of an epiphysial plate is well known. The plates in the rabbit's tibia conform to the classical description. The cells are arranged in columns and their form is graduated according to their position, those that are closest to the epiphysial surface being the smallest and most compressed, and those near the metaphysial surface being the largest. The cartilage plate is sandwiched between two bony layers: on the metaphysial side the trabecular bone of the shaft, and on the other side that condensed part of the epiphysial shell known as the terminal bone plate. This plate is perforated to allow passage of the epiphysial vessels to the subchondral region.

Blood supply of the epiphysial plate—Blood reaches the epiphysial plate from three sources—the epiphysis, the metaphysis and the circumference of the plate.

The epiphysial supply—The epiphysial surface of the plate is supplied by the terminal capillary loops of the epiphysial arteries. Up to about two dozen such loops arise from each of the arteries which pierce the terminal bone plate, so that the capillary loops from each artery are spread over a localised area. The loop is thick and wide and frequently presents a flattened or expanded end. The loop itself pierces the final calcified subchondral layer of the epiphysis so as to appear through a small opening at the summit of from eight to twelve columns of proliferating epiphysial cartilage cells, the rounded tops of the columns inclining towards the central aperture in the calcified zone (Fig. 14), and between the hole and the columns one

FIG. 12
Spalteholz preparation. Thick section (unstained) of lower tibial epiphysis. Nutrient artery appears black.

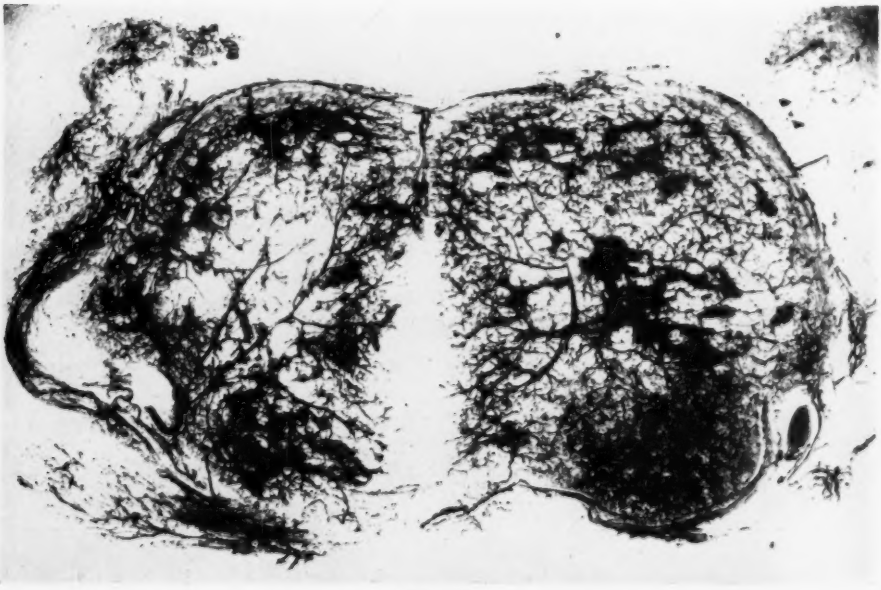

FIG. 13
Microradiograph of thick transverse section of lower tibial epiphysis.

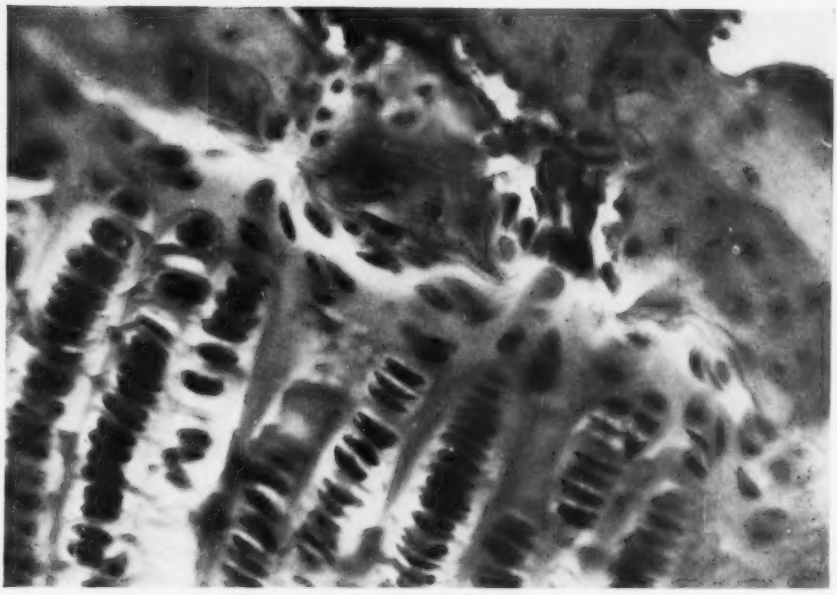

FIG. 14

Photomicrograph of epiphysial plate, stained with haematoxylin and eosin. Two epiphysial capillary loops are seen at the summit of diverging columns of cartilage cells.

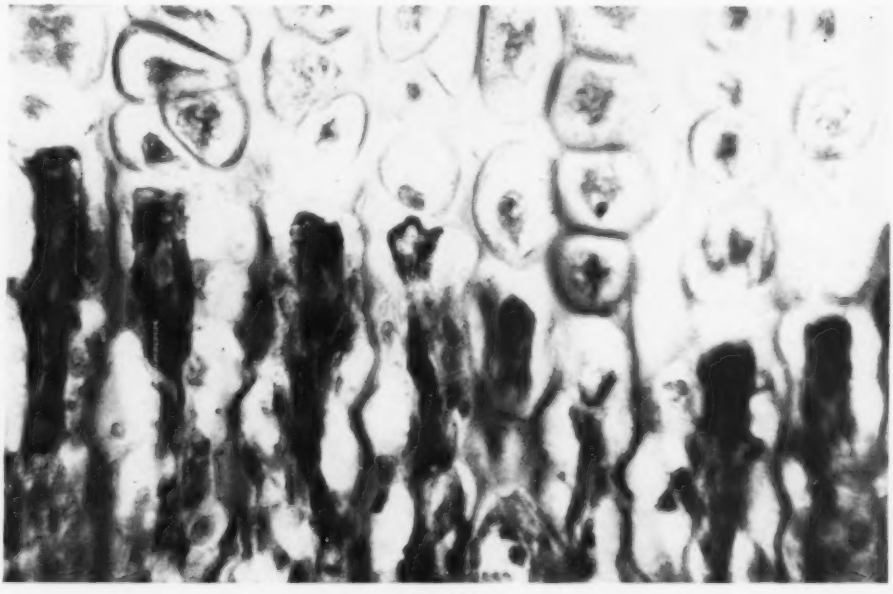

FIG. 15

Photomicrograph of epiphysial plate, stained with haematoxylin and eosin. Several metaphysial capillary loops are seen, each related to a single column of cells.

frequently sees one or two dark-staining, rather long narrow cells. The other end—the venous end—of the loop passes to the collecting vein and back through the bony shell of the epiphysis into the sinusoids.

The metaphysial supply—The metaphysial surface of the plate has a much more dense arrangement of vessels supplying it. These take the form of a brushwork of capillary loops which are the terminal ramifications of the branches of the nutrient artery of the tibia.

Each loop runs a long, straight course towards the end of a column of hypertrophic cartilage cells and is separated from neighbouring loops by a thin indented tube of calcified matrix. Each loop is normally associated with its own column of cells and reaches exactly up to the end cell (Fig. 15).

The circumferential supply—This is a very small artery, which runs around the periphery of the plate. It is formed by fine branches from the superficial anastomosis of the periosteal arteries (Fig. 16). The circumferential artery is therefore connected to both metaphysial and epiphysial circulations. It is probably the vessel concerned in the " perichondral ring of the ossification groove " (Lacroix 1951).

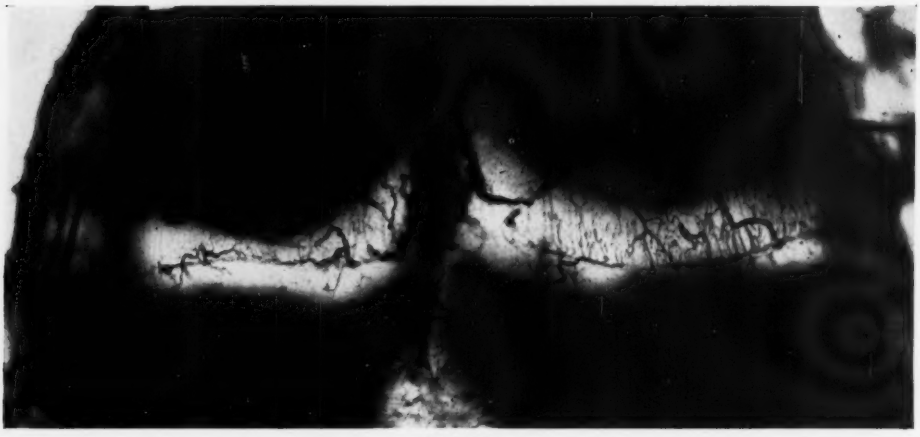

FIG. 16

Spalteholz preparation. Circumferential artery of the plate seen through translucent cartilage.

THE PERIOSTEAL ARTERIES

The periosteum of the growing rabbit has a rich blood supply, the arteries and accompanying veins forming a continuous vascular layer, which ensheathes the bones and joints of the leg.

In the region of the tibia the layer is represented by six or seven large arteries, which run from above downwards with little alteration in calibre. As the vessels pass close to the surface of the bone they give off numerous branches, generally at right-angles but in the same plane, and these form a network over the periosteum (Figs. 17 and 18). This network sends many fine branches into the cortex of the bone to supply its outer layer, but occasional branches pierce the whole thickness. A longitudinal view of the cortex of the shaft shows that the vessels occupy a series of channels which lie parallel to the surface of the bone, and are interconnected at intervals by vessels at right-angles, giving a lattice appearance, resembling the mortar in a brick wall (Fig. 19).

Periosteal arteries connect mainly with the superficial part of the lattice-work plexus: through the plexus they anastomose with the cortical branches of the nutrient arteries (Fig. 20). The number of such vessels is small in the centre of the shaft and greatest at the metaphysis,

FIG. 17

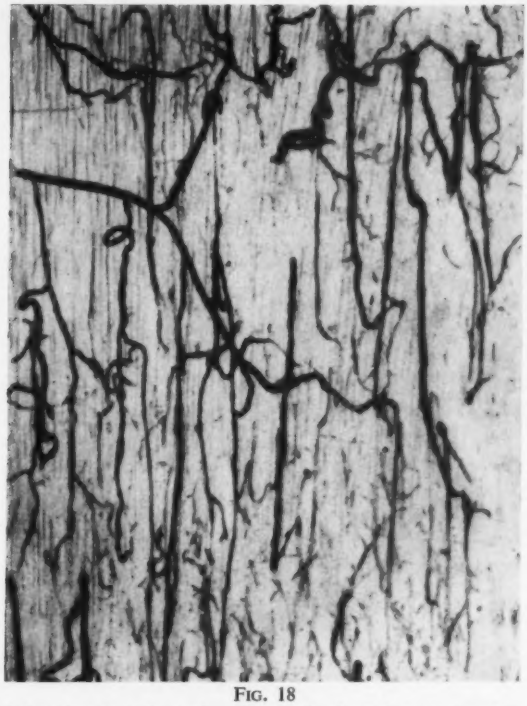

FIG. 18

Figure 17—Dissection of rabbit's tibia showing injected periosteal arteries. Figure 18—Spalteholz preparation. To show arrangement of branches of periosteal arteries over the bone cortex.

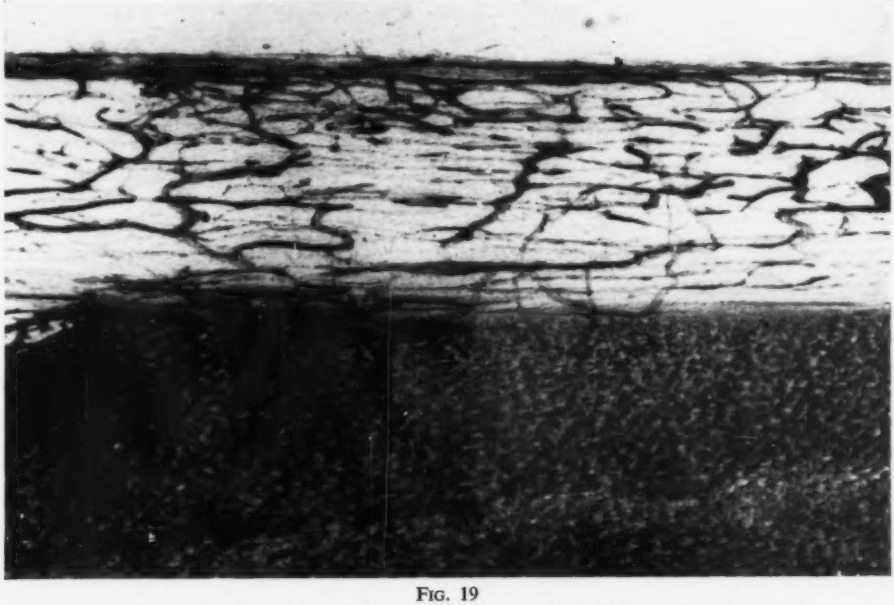

FIG. 19

Photomicrograph of thick longitudinal section of cortex, showing arrangement of vessels.

and in this situation they normally supply that peripheral part of the plate which overlies the spongy "cortex."

At both ends of the tibia anastomosis between longitudinal periosteal arteries takes place, the branches involved being arranged around the bone to form two circular series of vessels (Hunter 1743).

The smaller series is almost opposite to the epiphysial plate. Each longitudinal periosteal vessel sends branches of characteristic S-shaped form, which pass towards the substance of the

FIG. 20
Photomicrograph of thick section of tibial cortex (unstained). Injected vessels show black and demonstrate connections between periosteal and nutrient arteries.

plate and anastomose with the superficial arteries of the metaphysis and epiphysis. Small branches from this anastomosis form the principal supply to the circumferential artery of the plate.

The largest series is opposite the joint line. Branches from this plexus supply the nutrient arteries to the epiphyses, the menisci and other intra-articular soft tissues. It should also be noted that at the end of the bone, in the region of the metaphysis, there is a great interchange of venous blood between the medullary cavity and the cortex of the bone, the marrow and the venous sinusoids draining from the subchondral loops and the veins of the periosteal layer itself.

THE VEINS OF THE RABBIT'S TIBIA

Before describing the topography of the veins of the growing rabbit's tibia, the following features of venous drainage of bone should be considered: firstly, there is, in a long bone at least, one large centrally placed vein, which lies in the marrow cavity and has its exit through a foramen in the cortex. This vein is a large distensible vessel, but with an exit limited by a bony canal of fixed dimensions. It seems probable, therefore, that although the vein might dilate the exit could not, so that obstruction to the outflow would occur. Experimentally it is possible to fill up the vein until it is much larger than the emissary foramen. It would follow therefore that if this were the only exit for venous blood from the bone, it would not

FIG. 21

FIG. 22

Figure 21—Photomicrograph of thick longitudinal section of lower third of tibia (unstained). Sinusoids may be seen draining towards the central vein from metaphysial loops and from the periphery of the medullary cavity. Figure 22—Microradiograph (lateral view) of upper half of tibia, showing veins entering upper part of central vein.

be possible for more blood to come out of the bone than was put in, and *vice versa*, unless some way could be found to speed up the drainage from the emissary foramen by negative pressures produced outside the cortex acting on the exit of the central vein.

Secondly, the fixed and solid structure of the bone protects the marrow from the compressive pump-like action of the moving soft tissues around it, so that no expression of blood from the veins can take place, as happens in other parts of the body. Compression of the medullary veins could be supplied only by forces acting inside the bone, such as an increase in arterial flow or pressure, or by means of arteriovenous shunts in the substance of the bone or in the marrow cavity. The *vis a tergo* of the capillary loops would surely be insufficient.

FIG. 23

Photomicrograph of thick transverse section of upper tibial metaphysis (unstained), showing medullary sinusoids draining into veins which pierce the posterior cortex.

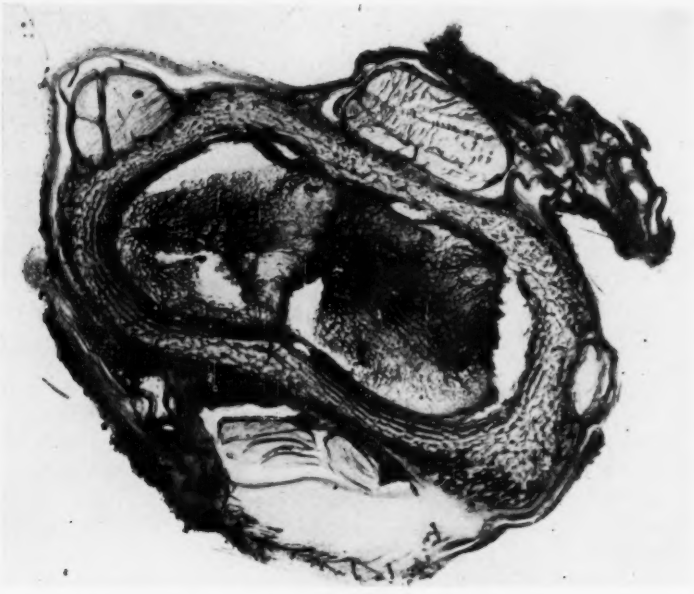

FIG. 24

Photograph of thick transverse section of lower tibial metaphysis (unstained), showing medullary sinusoids draining into central veins and connecting through the "cortex."

In fact, however, a bone is not nearly such an impervious structure as it appears, for at the ends of the shaft an enormous number of potential channels do exist, which connect the inside of the bone with the outside; a much smaller number of openings penetrate the middle portion of the shaft. The region of the metaphysis of the growing bone is a veritable sponge-work of canals, mainly occupied by veins and connected with the general venous drainage system of the leg. It seems likely, therefore, that blood may pass in or out of the extremities of the bone with some ease during the alternate systole and diastole of muscular action and with greater difficulty negotiate the single narrow emissary vein in its bony passage.

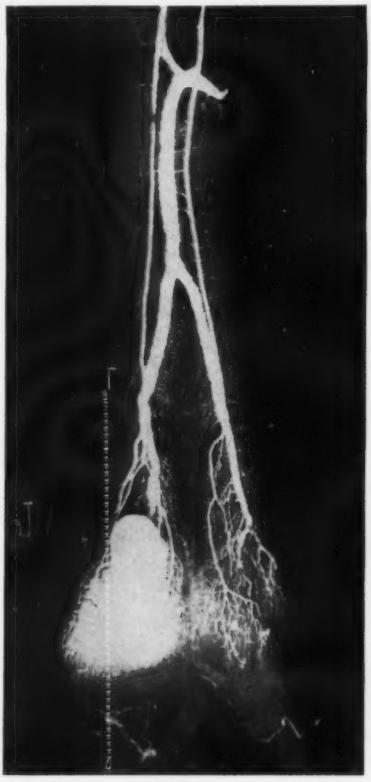

FIG. 25

FIG. 26

Figure 25—Angiograph of lower half of tibia, showing form of great central vein. The " burst " obscures the terminal part of the vessel on the medial side. Figure 26—Spalteholz preparation. Herring-bone pattern of sinusoids, with " beaded " central vein.

Topography of the venous drainage—Venous blood in bone is generally contained in the vessel known as a sinusoid. Initially the sinusoids appear to be filled from the venous half of the metaphysial loops in the subchondral region of the epiphysial plates, but further drainage occurs from the periphery of the marrow cavity, probably through connections with the arterial " net " (Fig. 21).

The central vein is formed by the conglomeration of the venous sinusoids, which can be seen entering the entire length of the vessel; it seldom has any large tributaries except near the upper metaphysis where a series of veins are seen, which drain the upper part of the

marrow cavity and are arranged in the form of a fan—most easily demonstrated in a lateral view of the bone as the vessels run from before backwards (Fig. 22). Connected with these veins are many anastomotic venous channels which pass through the metaphysial " cortex " of the bone to join the periosteal plexus of veins before entering the general venous system. These are large and commodious vessels and are easily seen in transverse sections of injected bone (Fig. 23). Such an arrangement also occurs at the lower end of the tibia, but in this situation the channels are neither so well defined nor so large, although they are very numerous (Fig. 24).

The great central vein—The great central vein in the rabbit's tibia is formed about the middle of the tibia by the junction of the medial and lateral central veins, which collect blood from the sinusoids of the respective halves of the lower metaphysis. It then passes upwards as a

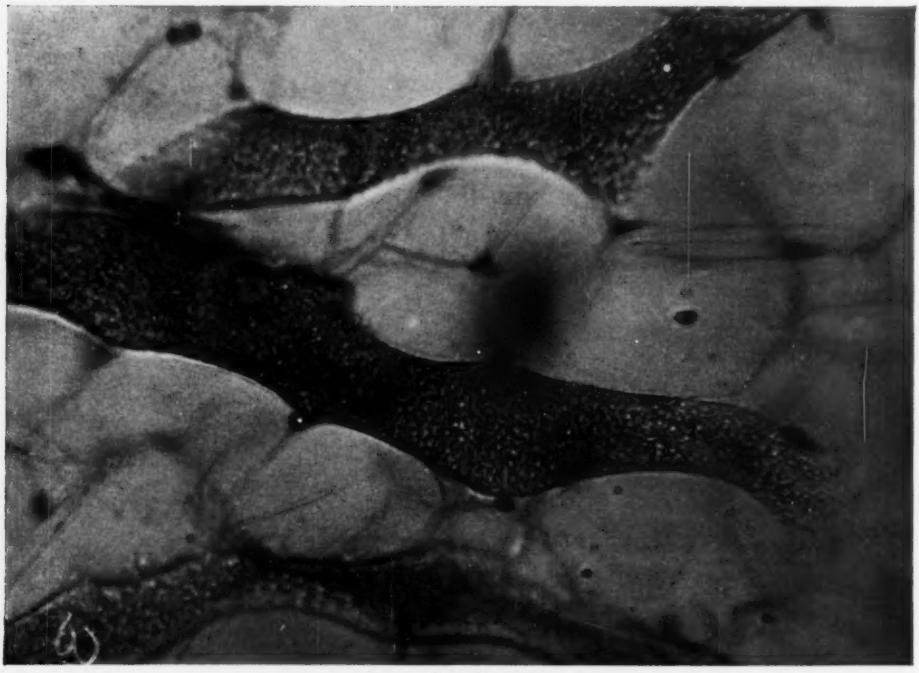

FIG. 27

Microradiograph showing dilated sinusoids separating fatty cells of the marrow.

single vessel to join the large vein from the upper half of the tibia and, turning sharply, pierces the cortex through the emissary foramen, which lies below and anterior to the entrance of the accessory nutrient artery (Fig. 25). The great central vein is variable in size and in the manner of its formation. When slightly filled it is a thin tenuous vessel with a beaded appearance, the collecting sinusoids joining the central vein in a " herring-bone " pattern (Fig. 26); but when the venous sinusoids themselves are filled the vein appears as a wide vessel with a regular fringe of sinusoids converging on it from the periphery of the marrow. In such conditions the sinusoids are seen as many parallel channels arranged obliquely and separated from each other by a layer of marrow cells (Fig. 27). Sometimes it may enlarge to an enormous diameter, to fill a third of the whole marrow cavity with its sinusoids dilated and misshapen—a physiological giant and a veritable reservoir of blood.

In this paper the general scheme of blood supply to a long bone has been described. No attempt has been made to correlate the arrangement of the vessels with the function of the part, because this will form the basis of a further contribution; nor has the reason for the special form of venous drainage been established.

The study of the circulation of the blood in bone and marrow and the changes which occur in the vascular field with growth and age is not yet complete.

I would like to thank Professor J. Trueta for his constant help and encouragement, Mr D. W. Charles for his care of the animals, Mr R. Hill and Mr A. Mann for the preparation of the specimens, and the photographic department of the Nuffield Orthopaedic Centre.

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JONATHAN DOBSON
1907-1958

Jonathan Dobson qualified in medicine in 1931 and, after a period as house surgeon at the Manchester Royal Infirmary and Bootle General Hospital, he spent some time as a ship's surgeon, doing two trips to the Far East. He eventually joined the Lancashire County Council Tuberculosis Service at Wrightington in 1934. Two years later he was appointed Deputy Superintendent and in 1944 became Surgeon Superintendent.

He was very well loved by all the staff and his colleagues, and never had an unnecessarily critical word for anybody. He wrote authoritative papers on bone and joint tuberculosis for publication in the British edition of the *Journal of Bone and Joint Surgery*: " Arthrodesis in tuberculosis of the hip joint " (1948); " Prognosis in tuberculosis of the hip " (1951); " Tuberculosis of the spine " (1951). He lectured at the European Congress on Orthopaedic Tuberculosis in Vienna in 1955. He was elected to Fellowship of the Royal College of Surgeons *ad eundem* in May 1953. His opinion was often sought by colleagues both at home and abroad in matters of orthopaedic tuberculosis. H. B. A.

B. L. M. writes: Dobson was a very remarkable man. From a position which, in other hands, might have been insignificant, he exerted considerable influence on orthopaedic practice as far as tuberculosis was concerned. He was a great help to the Liverpool School of

Orthopaedic Surgery. Regularly year by year our postgraduate students studied daily under him for a week or more at a time. His value lay in his inflexible honesty, his intelligence, his insight, and his patience and carefulness. Withal, he was a most agreeable companion, and we in Liverpool are sorry we shall not meet him any more.

A postgraduate student in the Liverpool School of Orthopaedics wrote in his thesis: My sincerest gratitude is to the late Mr J. Dobson, whose recent sudden death came as a stunning blow to all of us who have been deprived of a good, kind and sympathetic teacher. He will be remembered by us with love and admiration.

JAN ZAHRADNÍČEK
1882-1958

Jan Zahradníček was born on June 13, 1882, at Mastník in Moravia. After qualifying in 1909 he studied surgery under Professor Otakar Kukula in Prague, but his career was interrupted first by the Balkan War and then by the first world war, throughout which he served as surgeon to the forces. Returning to Prague after the war, he took up the study of orthopaedic surgery, which he determined to make his career. In 1931 he was appointed head of the First Clinic for Orthopaedic and Children's Surgery at Charles University in Prague, where he continued to work until the time of his death.

Under Zahradníček's guidance orthopaedic surgery achieved a high standard in Czechoslovakia between the two world wars. One of his main interests was the surgery of the hip, and he was an early advocate of derotation osteotomy of the upper end of the femur for congenital dislocation of the hip. He was a founder member of the Czechoslovak Orthopaedic Society, and of the International Society for Orthopaedic Surgery and Traumatology, a member of the French Surgical Academy and the International Surgical Association, and an Honorary Member of the French Association for Orthopaedic Surgery. For many years he had been Editor of the official journal of the Czechoslovak Orthopaedic Society.

Zahradníček had come to be regarded as the " father of orthopaedics " in Czechoslovakia, and he will be sadly missed. M. J.; V. T.

PROCEEDINGS AND REPORTS OF UNIVERSITIES COLLEGES, COUNCILS AND ASSOCIATIONS

GREAT BRITAIN AND IRELAND

BRITISH ORTHOPAEDIC ASSOCIATION: AUTUMN MEETING 1958

The Fortieth Annual Meeting of the British Orthopaedic Association was held on October 2–4, 1958, at the Nuffield Orthopaedic Centre, Oxford, under the presidency of Mr Norman Capener.

FIRST FOUNDER'S LECTURE

Sir Harry Platt (Manchester) made the meeting memorable by his delivery of the first Founder's lecture, to mark the fortieth anniversary of the founding of the British Orthopaedic Association in November 1918. Under the title **" Quick, thy tablets, Memory! "** he described with charm and rhetoric his memories of the Association's earliest years and of the great personalities with whom he was associated in its foundation, and gave us too his thoughts on where our future lay. The lecture will be reported in full in a later issue of the Journal.

SCIENTIFIC PAPERS

The blood supply adjacent to the epiphysial plate and its influence on growth—*Professor J. Trueta* (Oxford) said that since the early description of the growth plate by Sharpey, Tomes, de Morgan, H. Muller and others, over 100 years ago, the epiphysial cartilage had been the place where enchondral ossification had been more profitably studied, but even so inadequate information still existed on the role of the blood vessels in this type of osteogenesis. For the last ten years they had in the laboratories at Oxford studied the vascularity of bone, and in this short paper a summary of the contrasting shape, size, number and arrangement of the vessels adjacent to each of the sides of the growth plate was described. They had collected data suggesting that the vessels reaching the plate from its epiphysial side had a function mainly nutritional of the repeatedly dividing cartilage cells, whereas the peculiarly arranged vessels underlying the plate from its metaphysial side were mainly, and perhaps only, concerned with the calcification of the giant cartilage cells. The experimental surgical interruption of these metaphysial vessels, or their occlusion by pressure, caused a total failure not only of calcification but also of the degeneration of the giant cells, showing that calcification was the essential prerequisite to degeneration. A picture both radiographically and histologically similar to rickets was thus obtained, and growth was consequently affected.

His colleagues would suggest in the two following papers some practical and clinical consequences of these vascular studies.

Some factors influencing the growth of the human femur—*Mr J. D. Morgan* (Oxford) recalled that the epiphysial plate matures only when ossification of the shaft has extended sufficiently to form the metaphysial end plate, subsequent growth being in the direction of the cartilage cell columns which form at right angles to the base of the plate. At the upper end of the femur the metaphysial end plate was wedge-shaped, growth in length being proportional to the angle formed and probably at first equal to that at the lower end. The two sides of the wedge eventually separated as the epiphyses for the head and greater trochanter developed, but at first most of the growth in length came from the capital side, resulting in the coxa valga which was normal in infancy and which persisted if the trochanteric epiphysis for any reason closed prematurely. If the capital epiphysis closed early from congenital deformity, injury, infection or paralysis, the trochanteric epiphysis took over control of longitudinal growth, and any operation in such circumstances must therefore avoid damaging the latter. It was only if both parts were closed that gross shortening occurred. At the lower end interruption of growth commonly affected only part of the epiphysial plate, resulting in both shortening and distortion of the bone. Ischaemia, as in Perthes' disease, promoted growth in circumference of the epiphysis and hence widening of the bone. Disuse of the lesser trochanter, as in iliopsoas paralysis, resulted in failure of this area of the shaft to thicken normally.

Congenital coxa vara—*Mr E. W. Somerville* (Oxford) based his argument on a patient whose mother had injured her abdomen six weeks before term. When the child was eight months old the capital epiphysial centre first appeared radiographically, in its normal position, together with a " ghost " of

the missing neck and upper femoral shaft lying at an angle to the bony lower part of the shaft. Arthrography and exploration confirmed these findings, which he considered to be due to an intra-uterine fracture of the cartilaginous femur. As a result primary ossification of the shaft, depending on its nutrient artery and the capillary loops formed from it, had been brought to a halt at the fracture site, and the metaphysial region had failed to ossify. In such circumstances an epiphysial plate did not develop, and ossification occurring normally in the ossific centres of head and greater trochanter, where the blood supply was intact, spread unhindered into the metaphysial region where irregular ossification later occurred in accordance with the local blood supply. Examples were shown to illustrate this process; growth in length was no longer possible at the upper end of the femur. Mr Somerville thought that the fact that the inferior epiphysial artery supplied also the lower part of the neck could account for the presence of the triangular fragment of bone so commonly seen in this region in this condition, and that there could be a small area of normal epiphysial plate between it and the adjoining part of the capital epiphysis. If such secondary ossification occurred fast enough elsewhere in the neck some sort of epiphysial plate might develop there also, but not such as could produce any significant growth in bone length. Damage very high up to the ascending branch of the nutrient artery of the shaft might prevent the formation of a metaphysis to the neck while preserving that to the greater trochanter, with the result that growth in length occurred here and the neck was left behind. *Sir Reginald Watson-Jones* (London) thought that this and similar conditions in this region were all due to birth fractures through cartilage. *Mr David Trevor* (London) asked why, if that were so, the condition was so commonly bilateral, and *Mr J. C. Scott* (Oxford) asked for an explanation of the frequent association of other congenital defects and of a familial incidence. *Mr Somerville* agreed that many instances were not explicable as fractures but thought that basically the underlying abnormality was one affecting the local blood supply rather than the cartilage itself.

Arthrodesis of the shoulder in the reconstructive surgery of paralysis of the upper limb—*Mr D. M. Brooks* (London) and *Dr A. Zaoussis* (Athens) said that this operation had a doubtful reputation, was technically difficult and was not always productive of a satisfactory functional result. Of fifty operations between 1943 and 1957 twenty-eight were for brachial plexus injuries, and thirteen of the patients had an amputation at the same time as the arthrodesis. Failures of fusion in six of the latter were considered to be due to the difficulty of plaster fixation in these circumstances. The authors recommended a method in which the acromio-clavicular joint was preserved and the spine of the scapula was excised and used as a graft thrust through a hole drilled through the humeral head into the glenoid. Position was important only in regard to subsequent function. Abduction power was not useful unless rotation was controlled, and trapezius and serratus magnus were important in this connection; the average rotation range was 80 degrees. The disadvantages of the operation included limited rotation, limited extension and inability to sleep lying on that side. Fusion of the shoulder could increase the power of both flexion and extension at the elbow. The provision of adduction power, enabling the patient to grip an object between the arm and the body, was more valuable than the power of abduction, which should not be the primary object of the operation. The authors concluded that the procedure was a satisfactory one for a patient with a flail shoulder and good scapular muscles and recommended the position of 30 degrees' abduction, no flexion and 45 degrees of medial rotation. Answering questions, *Mr Brooks* thought it wise to delay operation until after epiphysial closure, and that it was potentially useful in both partial and complete brachial plexus lesions.

Anterior vertebral fusion—*Mr W. de Wytt* (Dublin) reviewed forty-five cases. At first the operation was tried out in quiescent cases of tuberculosis as an alternative to the mechanically unstable posterior fusion, but the dense paravertebral fibrosis made the procedure extremely difficult and liable to damage important neighbouring structures. For the early case, however, he had found it so satisfactory that he now used it in all suitable patients after one month's preliminary treatment with antibiotics—a routine sufficient to prevent sinus formation—which was continued for the next six months. The patients were aged from ten to fifty-five years, with twenty-six thoracic lesions, four thoraco-lumbar, thirteen lumbar and three lumbo-sacral. In thoracic lesions a transpleural approach was used: he had found this much simpler and less traumatic than postero-lateral decompression. For low thoracic and thoraco-lumbar lesions he excised the tenth or eleventh rib and divided the diaphragm in the line of incision from the tip of the rib to the left crus. Lumbar lesions were approached retroperitoneally through a lumbar sympathectomy incision. A transperitoneal approach through an anterior midline incision with the patient in the high Trendelenburg position was used for lumbo-sacral disease, the posterior peritoneum being split over the beak of the sacrum. After the lesion had been cleared out and any exposed dura covered with a muscle graft, an iliac, tibial or rib graft was slotted into the vertebrae above and below as a strut and the cavity was packed with bone chips: chips alone did not provide sufficient support and they permitted further angulation. The approach was always from the

left side. After three months in a turning frame, the patient was allowed up in a spinal brace for one year and then returned to work, usually manual labour. There had been no recurrence, but one patient had died after this operation. Mr de Wytt had found it a most satisfactory operation for patients with paraplegia. The complications were listed and he considered them nearly all avoidable by careful technique.

Principles of free tendon grafting, including a new method of tendon suture—*Professor Paul Brand* (Vellore) illustrated his contribution with a film of outstanding quality and clarity, showing the removal of a plantaris graft and its use in his operation for intrinsic paralysis of the hand. The principles he so convincingly propounded he summarised as follows: " Tendon transfers are more regularly successful than tendon free grafts because they have no suture line in the length of the tendon to cause adhesions, and because they carry their own blood supply and therefore do not need to grow new blood vessels which attach them to surrounding structures along their length. Frequently, however, it is difficult to spare a muscle with a long enough tendon, without causing secondary disability from the loss of the muscle's original function. In such cases a tendon free graft from a more proximal muscle may be necessary. Secondary deformities following the Bunnell sublimis operation have led us to use a new operation using free grafts from a wrist-moving muscle. During the carrying out of 200 tendon free graft operations for intrinsic paralysis of the hand we have worked out new methods which have improved their effectiveness by minimising adhesions around the grafts. The plantaris tendon is ideal grafting material. Its length, the abundance of its paratenon and the fact that it can easily be spared are all important factors. The new method removes this tendon by using a tendon stripper through one short incision, coring out the tendon from inside the muscle. Most failures in tendon grafting are associated with adhesions at the tendon suture line. The chief difficulty is to prevent ' unsatisfied ' tendon fibres from attaching themselves to surrounding structures. A new method has been developed which ensures that all of the cut ends of both the motor tendon and the tendon graft are entirely embedded within the substance of the other tendon. Most tendons are made up of sheets. Thick tendons are usually rolled-up sheets and a hilum can be observed running along the deep surface of the tendon. Such tendons may be split open along the hilum and opened out into a sheet. Thin tendons, such as the palmaris and plantaris, which have a paratenon covering, can be stretched into a sheet simply by pulling on the edges of the tendon with needle-pointed forceps. These fine tendons may be stretched into a sheet two inches wide. The new method is to open out the motor tendon and the tendon graft into flat sheets at their ends and then to allow each tendon to engulf the end of the other by wrapping it up in the sheet, which is rolled around it. This makes quite certain that no free end of either tendon can grow onwards and attach to any other structure. The use of paratenon is also important. The paratenon surrounding the plantaris or palmaris tendons should be rolled down like a sleeve before the tendon suture, and then rolled back again like a sleeve over the tendon suture, thus minimising the chance of lateral attachments. Free tendon grafts always have to obtain their blood supply from surrounding structures; therefore they are always attached to the structures which line their path. In the raising of any flap rigid structures such as fibrous septa and retinaculae are inevitably divided. The scar which is common to the whole wound will therefore form an attachment between these rigid structures and the new tendon graft. It is therefore urged that flaps should never be raised in tendon free-graft operations. The tendon suture should take place outside the limb after the motor tendon has been withdrawn through a proximal buttonhole incision. The graft is then tunnelled back through the soft fatty tissues using a blunt-nosed tendon tunneller. The surgeon must feel his way between rigid or important structures, helped only by his knowledge of anatomy, his sense of touch and patient determination not to push his way through any resistant structure. Like an earthworm feeling its way through the soil amongst roots and stones, he will eventually find a path through the tissues without damaging any rigid structure. The attachments of the tendon will then be to soft and slippery fatty material which will not restrict the mobility of the tendon significantly. A new operation for intrinsic paralysis of the hand is described. This involves the use of the extensor carpi radialis longus or brevis muscle, extended by four tendon grafts through the interosseous spaces of the hand, anterior to the transverse metacarpal ligaments, to be inserted at the edge of the dorsal expansion of each finger."

The use of bone grafts in malposition and non-union of fractures of shafts of long bones—*Mr R. G. Taylor* (Oxford) reviewed seventy-two grafting operations performed between 1950 and 1955, of which two-thirds were done for fibrous union, and the remainder early for malunion, at an average period of three weeks after the fracture. If closed reduction failed or needed repeating more than ten days after the fracture, he considered open reduction and fixation by grafting to be usually the method of choice. In analysing the causes of fibrous union he noted that no case had occurred in 200 consecutive tibial shaft fractures, both simple and compound, in patients under seventeen. Above this the age of the patient was not important, nor was the site of fracture. Two-thirds of the failures to unite by bone had occurred in

compound fractures, although these made up less than a third of the total fractures seen. The severity of the injury, loss of bone, loss of skin and infection were all factors making fibrous union more likely. He regarded repeated manipulations after the tenth day as particularly deleterious, as was distraction from any cause. He recommended the use of a combined onlay and inlay graft, firmly fixed with four screws. The fibrous zone was resected only if the bone ends needed realignment. In the seventy-two cases there were eight infections, of which seven occurred in previously compound fractures. Among these were the only two failures to produce bony union. The average period of total immobilisation for tibial grafts was 104 days, with a further forty days in a gaiter for two-thirds of them. *Professor Bryan McFarland* (Liverpool) said that he did not use screws, being satisfied with impacting the grafts into position. *Professor R. Soeur* (Brussels) thought it was sometimes better to graft selected fresh fractures as a primary procedure if one had reason to suspect that delayed union was likely to occur. *Mr J. N. Wilson* (London) said that it was unphysiological to use a graft for fixation. He preferred the simpler and easier cancellous strip method. If fixation was required a plate should be used. The *President* pointed out the potential danger of a plate in holding the bone ends apart. *Mr Taylor*, replying, thought it was an error to add any further unessential trauma to an already traumatised limb, and said that cancellous strips alone were not suitable for bridging gaps and that he had no doubt that his inlay grafts were osteogenetic.

An experimental comparison of bone-grafting materials in the dog—*Mr J. Chalmers* (Edinburgh) and *Dr H. A. Sissons* (London) reviewed their experiments. In young adult dogs a cavity prepared in the cancellous bone of the lower part of the femur was filled with bone chips of standard size prepared from rib bone, either fresh or preserved by one of a number of procedures. The progress of the grafts was studied microradiographically and histologically for six to nine months. The rates of removal of graft bone and of formation of reactive bone were determined from measurements carried out on drawings of the histological sections and gave an objective indication of progress. In each series of dogs two grafting materials were compared by inserting one into each femur. The types studied were fresh autograft, fresh homograft, frozen homograft, autoclaved homograft, freeze-dried homograft, deproteinised bone, decalcified homograft and freeze-dried irradiated homograft. The results showed measurable differences, fresh autograft stimulating rather more new bone formation than fresh homograft. All types however behaved in the same general way and the differences with few exceptions were unimportant. No graft showed surviving osteocytes. They suggested that the choice of method of preservation for banked bone could be governed by convenience rather than because of any significant biological advantage of any particular method, and they thought that freeze-dried bone sterilised by gamma irradiation had considerable practical advantages.

Traumatic dislocation of the hip in childhood—*Mr J. Piggot* (Exeter) recalled that traumatic dislocation of the hip was rare in children. Nine had been treated at Exeter, five boys and four girls, the youngest aged four and a half years, the eldest fifteen years; the patients had been followed for an average period of five years. In one child avascular necrosis of the femoral head had become apparent after six months, a finding that he compared with the incidence of not less than 10 per cent of this complication in adult series. In one instance reduction was delayed for four days, a fractured shaft of femur in the same leg having distracted attention and delayed diagnosis. Two patients were noted to have a wide joint space on the radiograph after reduction; this widening might last for several weeks and he considered it possibly due to interposition of the torn labrum. Both patients had been left with slight limitation of movement, but all the patients were symptom-free at present. He had found no evidence that avoidance of weight bearing had prevented the onset of avascular necrosis. *Professor Bryan McFarland* (Liverpool) wondered whether the increased joint space had been due to blood clot, as found by Patterson of Vancouver when he had opened a similar hip because the head was lying eccentrically. *Mr H. D. W. Powell* (Manchester) said that in an inquiry being undertaken by Mr A. Glass and himself they had found four instances of avascular necrosis in the fifty-one cases so far collected from various sources in Britain. *Mr S. M. Thompson* (Grimsby) had encountered one case in which an eccentric reduction had been ascribed to interposition of a large mass of muscle. *Mr Piggot*, replying, thought that any higher incidence of avascular necrosis in adult dislocations was due to differences in the local blood supply, with the added possibility that a dislocation might occur with less trauma in the child due to the high proportion of cartilage.

The use of cortisone in tenolysis—*Professor J. I. P. James* (Edinburgh), on the supposition that Carstam's work on the effectiveness of cortisone in preventing tendon adhesions in rabbits might be applicable to the human, and after noting the disappointing results of his small series of tenolyses without cortisone, had combined the operation with the administration of A.C.T.H. or cortisone, begun two days before operation and continued for fourteen days thereafter. Dosage now used was 150 milligrams

of cortisone daily, with " weaning " to follow; the usual precautions were taken. Dressings were changed after two days and active exercises started: sepsis had not been a problem. He reported the results in twenty-two patients. Although there had been some failures the results in general were better than after tenolysis without cortisone. Rapid improvement after operation was likely in successful cases, and a prognosis could usually be given within two weeks. He had not noticed that cortisone had helped in the few cases of tendon grafting he had done under its cover. The results in tenolysis were encouraging but required confirmation by further work.

Low back pain on the basis of vascular insufficiency—*Dr David L. Filtzer* (Baltimore) reviewed fifty patients who had been under the care of Dr H. T. Bahnson and himself at the Johns Hopkins Hospital, of whom forty-three were men. All had suffered occlusion of the lower aorta or the common iliac arteries; 22 per cent had back pain of major or minor degree. In many a multiplicity of other diagnoses had been made and treatment given accordingly before the true cause was elucidated. All the occlusions had been proven by aortography or operation for endarterectomy or replacement by a homograft, which procedures had relieved the back pain. He stressed that a tentative diagnosis of vascular insufficiency should be considered in every patient with backache, and emphasised particularly the importance of the history. He considered that back or leg pain coming on after exertion and rapidly relieved by rest, with fatiguability of thighs and calves, with numbness and tingling of the legs, with a " dead feeling," with coldness of the legs and feet and with loss of potentia, should clinch the diagnosis even without laboratory aids. Palpation of the femoral and peripheral pulses must be part of the routine examination of all patients with low back pain. Answering questions, *Dr Filtzer* said he thought backache could arise from vascular causes other than a major obstruction. Even this might cause no more than weakness or slowness, without any pain, but he believed that the peripheral pulses, especially the femoral, were always diminished in such cases. It was possible that such an occlusion might cause an acute attack of backache, as could a dissecting aneurysm. It was of course possible to suffer an acute disc lesion coincident with a major vascular obstruction.

Carpal mechanics and trauma—*Mr M. Squire* (Reading) had studied the movements that take place between the carpal bones. Forced radial deviation produced torsion of the scaphoid bone and the trapezium was always forced forwards; the proximal part of the scaphoid bone extended and was under compression, and a twisting force occurred at the waist of the bone. Forcing ulnar deviation produced a lateral shift of the proximal row of the carpal bones, which were compressed against the resistance of the scaphoid. From these considerations he deduced that the distal fragment of a scaphoid bone fractured at the waist, in spite of the apparent mechanism of the injury, lies pronated. If any displacement had occurred it could be reduced by manipulation of the wrist into full extension, ulnar deviation (to impact the fracture) and supination. This position was held with an above-elbow plaster, at least for the first three or four weeks, and was also successful in closing the gap often seen between the scaphoid and the lunate bone in similar injuries. He said that this method rapidly reversed apparent radiographic ischaemic changes which did not prejudice bony union. He reported thirty unstable fractures of the scaphoid successfully treated by this method, with rapid union in most. *Mr F. W. Holdsworth* (Sheffield) expressed the difficulty of many in understanding the speaker's argument, and thought that such scaphoid fractures were more of a bursting injury due to the scaphoid's being screwed down the slope of the radius. He would hesitate to use this type of plaster. *Mr H. J. Seddon* (London) said that cineradiography of the movements of the carpus had shown that Mr Squire's analysis was correct.

Correction of the pronated foot—*Mr G. K. Rose* (Shrewsbury) reported the results of his studies. His paper was published in full in the November 1958 issue of the Journal.

Ectopic ossification in paraplegia—*Mr J. W. Dickson* (Sheffield) recalled that in traumatic paraplegia large masses of bone may be formed, especially in the iliacus, the adductors, and near the medial femoral condyle. Ossification might progress to extra-articular ankylosis of the hip and removal of the new bone might be required, in selected cases, if patients were to walk or to use a wheel-chair. The condition bore only a superficial resemblance to myositis ossificans progressiva. Radiographically the hip and knee joints showed little or no abnormality, in contrast to the better known neuro-arthropathies. There was no correlation between the distribution and extent of ossification and the level (if any) of the neurological lesion, ulceration, sepsis, spasticity, flaccidity or blood chemistry. The bone arose in muscle far from periosteum, and not from periosteal tearing, as had been suggested. It was not necessarily a simple ossification of haematoma in de-afferented tissues, as it occurred in a wide variety of nervous disorders, with motor, sensory and combined deficit. The indications for removal of the ectopic bone were described, together with operative technique, the gross and microscopic pathology, and the general management of cases. Reference was made to the pioneer work of Ceillier (1920) carried out under Professor and Madame Déjerine.

CLINICAL MEETING

An admirable collection of clinical material and scientific demonstrations was displayed in the new building of the Nuffield Orthopaedic Centre, the fruit of yet another munificent donation by Lord Nuffield; they included exhibits by *Mr G. P. Arden* (Heatherwood) on the use of radioactive phosphorus in estimating the blood supply to the femoral head after fracture of the neck, and by *Mr C. J. Kaplan* (Durban) on a posterior approach to the hip joint.

INSTRUCTIONAL COURSE

Before the meeting proper, a day was devoted to an Instructional Course, at which the following were the lecturers: *Professor J. Trueta* (Oxford) on "Osteomyelitis," *Mr J. C. Scott* (Oxford) on "The organisation of an accident service and the treatment of major fractures," *Squadron Leader C. Wynn Parry* (Royal Air Force) on "Electrodiagnosis," and *Dr Arthur I. Spriggs* (Oxford) on "Changes in bone in blood diseases."

SOCIAL EVENTS

Annual Banquet—On the evening of October 3 a banquet was held at Christ Church and was honoured by the presence of the Duchess of Marlborough and Lord and Lady Nuffield, with a few of the senior members of the University and of the Oxford Regional Hospital Board and the board of governors. The speakers included Sir Wilfrid le Gros Clark, Sir David Lindsay Keir, Master of Balliol, and Professor Joseph Trueta.

Robert Jones Golf Cup—This year's competition for the Robert Jones Cup was played at Frilford Heath Golf Club on October 1, 1958, as a prelude to the Autumn Meeting at Oxford.

Apart from odd showers the weather was kind. The course played long and heavy but this did not prevent Mr B. J. S. Grogono (London) from winning with the excellent score of 85−16=69. Second place was shared by Mr W. H. Maitland Smith (Doncaster) and Mr A. E. Bremner (Newcastle upon Tyne), each with a score of 74 net.

After the competition fourteen members dined together with the Captain, Mr Maitland Smith, in the Chair. It was decided to hold the next competition during the Torquay meeting at the end of April 1959.

ROYAL FACULTY OF PHYSICIANS AND SURGEONS OF GLASGOW

POSTGRADUATE CONFERENCE

A postgraduate Conference on Orthopaedics was held in the Royal Faculty of Physicians and Surgeons from November 17 to 21, 1958.

Rarefying Disease of Bone

On the first morning Professor E. J. Wayne took the chair at a session on "Rarefying Disease of Bone."

Osteoporosis—*Dr B. E. C. Nordin* pointed out that the concepts of osteoporosis had been framed by Pommer in 1885, and re-described by Albright in 1941. He defined osteoporosis as a loss of bone mass, where the relative proportions of mineral and organic material were preserved. In osteomalacia the mineral content was reduced in relation to the organic component, but these two diseases, osteoporosis and osteomalacia, might occur together. Osteoporosis would not show radiologically until 50 per cent of the bone mass was lost, and histologically detection was very difficult, because few standards were available. In 300 cases studied there were wide variations in the histology. About 10 per cent of all patients dying in hospital had some degree of osteoporosis.

Dr Nordin classified osteoporosis into *generalised primary osteoporosis*, which included idiopathic, post-menopausal and senile types, and *generalised secondary osteoporosis*, including hyperparathyroidism, Cushing's syndrome, thyrotoxicosis and possibly acromegaly, scurvy, diabetes, liver disease, Turner's syndrome, and eunuchoidism. There was also a localised form, including immobilisation, rheumatoid disease, and Sudeck's atrophy.

He described the radiological features of osteoporosis, especially the biconcavity of the vertebral bodies, and the cortex-medulla ratio of the second hand metacarpal, and of the femur. He described ninety-two cases which he had studied; thirty-two central, thirty peripheral and thirty of mixed type. The age averaged over fifty years, and there were seventy-seven females to fifteen males. Clinically, the main complaint was low back pain, and aching in the thighs. Kyphosis and loss of height might be present and the thorax tended to descend on to the pelvis so that pain occurred when the ribs impinged on the iliac crests. Biochemistry of the blood showed no abnormality, but urine calcium might be raised, normal or lowered.

In discussing the pathogenesis of the disease, he pointed out that it might be due either to diminished bone formation or to increased bone destruction. It was the modern idea that nitrogen

metabolism, as well as calcium metabolism, was affected—the matrix hypothesis. Sometimes lesions of the endocrine system were inculpated, as well as pure calcium defects. Dr Nordin thought that the reasons could be explained purely on calcium metabolism, quoting studies with radioactive Ca^{47}, and the fact that fractures in osteoporosis heal normally. The alkaline phosphatase in these patients was also normal. If the lesion of the bone were destructive, then the fault might be in calcium intake, calcium absorption or in calcium output. In his series all three lesions had shown in some cases. Calcium balance studies showed that many patients could be put into positive calcium balance by increasing calcium in the diet. Clinically, 79 per cent were improved by calcium and 6 per cent by calcium with vitamin D; only 15 per cent were not affected. He suggested that until modern studies were complete it was necessary to maintain an open mind on the pathogenesis of osteoporosis.

Osteomalacia—*Dr Ian Anderson* discussed the admissions of osteomalacia to the Victoria Infirmary over a ten-year period. He thought that there was a metabolic type of osteomalacia which was rare, and he pointed out that in his experience vitamin D deficiency had become extremely rare. Radiographs might not show any change, or there might be rarefaction of bone, but he agreed with Dr Nordin that 50 per cent of destruction was required before radiological signs became evident, though there might be thickening of the epiphysial line, or pseudo-fractures. There was a high alkaline phosphatase level.

He classified osteomalacia as follows:

Vitamin D deficiency. 1) Lack in diet. 2) Steathorroea—(*a*) idiopathic; (*b*) from diminished pancreatic function; (*c*) from localised disease of the gastro-intestinal tract; or (*d*) from biliary tract obstruction.

Renal tubular dysfunction. 1) Fanconi syndrome occurring in the infant, the adolescent or the adult. 2) Hyperchloraemic tubular acidosis (Butler-Albright syndrome). 3) Hyperchloraemic acidosis after uretero-sigmoidostomy. 4) Idiopathic hypercalcuria.

Vitamin D resistant osteomalacia, which might be considered by some people to be included in the group of renal tubular dysfunctions.

Hypophosphatasia.

Unknown.

Dr J. C. Eaton opened the discussion by pointing out the complexity of electrolyte balance studies, which include physical and organic factors. He thought that quantitative studies were required to clear up many of our concepts. He pointed out that vitamin deficiency might be due to therapeutic dietary deficiency, as in a patient of his who had been on a fat-free diet for years.

He pointed out that it was impossible to assess katabolism in patients after operation unless sufficient calories could be given to maintain caloric balance. He thought that the distinction between osteoporosis and hyperparathyroidism was difficult, and must await the estimation of parathyroid hormones in blood or urine.

Fracture of the Neck of the Femur

Treatment of femoral neck fractures by compression—*Mr John Charnley* (Manchester) reviewed the development and use of the compression screw which he and his colleagues had described previously. He began by stressing that subcapital fractures of the neck of the femur were quoted as having a 95 per cent rate of union in some centres, and suggested that this gave grounds for a more optimistic outlook in this fracture.

He gave a brief historical account of the methods that had been used to fix this fracture: the Smith-Petersen nail, the angled blade-plate, the sliding nail, the low-angle nail, and the four-wire fixation enjoying popularity in America at the moment. By analogy from methods of fixing two pieces of wood together, he showed that by far the best fixation was provided by a screw with spring loading. This had advantages over all other methods. It was particularly useful in the fracture under discussion, because it could compress the unstable fracture into a stable position, thus giving the greatest possible bone contact. He discussed the reasons for the details of the design; the importance of shaft fixation, the importance of the fixed angle of 120 degrees, and the importance of the width of the screw in the head. He felt that the appliance had a great advantage over sliding nails because one was often dealing with a dead head fragment and rigid fixation of the fracture was very important.

He referred to slight modifications of the design originally described which had made its use more satisfactory. This amounted to a shorter threaded area going into the head, a longer threaded distal end, a shorter sleeve, to avoid holding the fracture apart, and the removal of the sharp edge from this sleeve. The last modification was what he described as a " life-saver," which consisted in inserting a screw of half-inch overall diameter into the femoral head to replace the usual screw of five-sixteenths inch overall diameter with six threads in the bone. This screw was able to exert pressure on more than nine times as much bone as the original screw. He described its use in

clinical practice, emphasising the importance of studying the extrusion pattern on post-operative radiographs, and he showed how these patterns could be used to decide whether or not patients should be allowed to walk at any given time.

He postulated that there were degrees of ischaemia of the femoral head. The bone might have sufficient blood to survive but insufficient to repair the fracture, as well as the other extremes of complete viability and complete ischaemia. He thought that the compression screw was a research instrument into healing of this fracture. His claim was that its use would abolish the failures due to imperfect mechanical fixation, which amounted to 25 per cent of all fractures treated by the Smith-Petersen nail. He concluded by stressing the need for studying the extrusion pattern as a guide to follow-up, and stated that with intelligent use of this appliance it was possible to have an 85 per cent clinical success rate one year after the operation.

Treatment by nail and graft—*Mr James Patrick* stressed the value of the Smith-Petersen nail combined with a fibular graft, which he said had the great advantage that, as the nail became less tight, the graft was becoming solid. Thus the fracture was held firmly throughout, not only by metal but by living bone. He detailed the surgical technique, and showed the inadvisability of having too long a graft, and he stated that he had had 87 per cent of bone unions in his first series of cases. He stressed that the operation only took five minutes more than the Smith-Petersen nailing operation and gave better results.

Bone death—*Dr Mary Catto* gave a detailed account of the diagnosis of bone death from a study of a series of femoral heads removed at operation. She thought that bone death after this fracture was common; in most cases the removal of dead bone was greater than the formation of new bone after this fracture, but in a few cases new bone formation exceeded absorption, and this could account for the dense parts noted radiographically.

Discussion—*Mr J. Tulloch Brown* opened the discussion by comparing four series of cases he had treated by nail and graft, by Smith-Petersen nail, by compression screw, and more recently by a sliding nail of his own design. He felt that all these methods gave about the same proportion of unequivocal bone union at one year, and he felt that it was unwise to talk about clinical success as Mr Charnley had done, because this group included some cases of bone union as well as some cases whose prognosis was uncertain. *Mr A. G. M. Watt* and *Mr J. T. Marcroft* pleaded for prosthetic replacement in this fracture in certain older patients in order to obviate the prolonged avoidance of weight bearing that other methods entailed. The problem of diagnosis of complete ischaemia of the femoral head at operation was discussed and it was agreed that there was as yet no reliable method of solving this problem.

Spinal Injuries

Vertebral body fractures—*Mr F. W. Holdsworth* (Sheffield) classified spinal injuries into three main types: 1) crushing of the body; 2) rupture of the posterior ligament and the annulus, permitting dislocation; and 3) the rotational injury, in which the upper vertebra swung around the lower. This last injury was liable to be missed, and was by far the most unstable. Dislocation at the thoraco-lumbar level was usually a rotational injury, whereas dislocation at the cervical level was usually a simple anterior dislocation. The rotational injury at the thoraco-lumbar junction often caused paraplegia. Mr Holdsworth said that it was impossible to determine whether or not the fracture was stable, and how this could be perceived. Radiographs should be centred on the back of the neural arch, and not on the body of the vertebra. The slicing injury of the vertebral body was a common accompaniment of the unstable rotational fracture-dislocation. Cord damage and root damage were opposite the level of fracture, so that, at the L.1 level, the lumbar paralysis was due to root damage, and the sacral paralysis was due to cord damage.

Indications for plating a fracture-dislocation of the spine were well defined. Unstable fractures with neurological damage must be plated. Unstable fractures without neurological damage must not be plated. Patients with stable fractures should not have operation.

Neurological aspects—*Mr Joseph Schorstein* discussed the neurological aspects of spinal injuries. He traced the history of opinion to show how the erroneous idea that decompression by laminectomy might be beneficial had arisen and persisted. He did not believe that laminectomy was ever indicated in injury of the spine. Cord damage was inflicted at the moment of injury, and, though reduction of the dislocation might be desirable, laminectomy and especially division of the dura was highly dangerous. He thought that there was no such thing as haematomyelia, or cord pressure by intradural or extradural haematoma. He supported his views by an excellent series of histopathological studies of conventional and less conventional injuries.

The bladder—*Mr T. L. Chapman* discussed the management of the paralysed bladder. He described four types of bladder after the initial period of paralysis: 1) normal; 2) the automatic bladder; 3) the autonomous bladder; 4) the contracted bladder. He advocated the use of Gibbon's catheter from the first day. For the automatic type, he had treated spasticity of the bladder neck by resecting the neck, but with only moderate results. Pudendal neurectomy, subarachnoid alcohol block and division of the external sphincter were also mentioned. In the autonomous bladder, the patient must be trained to use abdominal wall pressure, and in this bladder neck resection was indicated only for severe fibrosis. He emphasised the importance of avoiding infection, and the efficiency of the automatic and the autonomous bladder increased when this had been avoided.

Plastic surgery—*Mr Ian McGregor* discussed plastic procedures for the effects of spinal injuries. He differentiated between the relatively shallow sacral pressure sore occurring in the early stages and the deep pressure sore with osteitis of the trochanter and ischium, occurring later when the patient sat up and used prostheses. He described the use of free skin grafts for temporary purposes and of rotational flaps for the ischial lesion. For severe ischial involvement he resected the ischium and swung a large, safe flap from the whole of the back of the thigh upwards.

Discussion—Discussion brought criticism of Mr Schorstein's views, which he upheld firmly. *Mr Ian MacKechnie* of Aberdeen showed a case of a large confluent ulcer involving the sacrum, ischium and trochanter. A compromise between free skin grafts for the sacrum and rotation flaps for the other areas was suggested. *Mr Holdsworth* agreed that plating for thoracic fracture-dislocation was indicated, but would not accept that it was ever indicated for unstable fracture-dislocation without neurological damage. *Mr Shedden Alexander* asked if the easier management of fracture-dislocation of the spine with paraplegia by the early use of internal fixation justified retention of these patients in units other than spinal centres. *Mr Holdsworth* did not see how these patients would ever be properly treated until each region possessed its own spinal centre, to which all patients with traumatic paraplegia were admitted at once.

Injuries of the Knee

Ligamentous injury and subluxation of the patella—*Mr I. S. Smillie* (Bridge of Earn) confined his attention to three important aspects of knee injuries which he stated occupied a fifth of the beds in his male wards. He began by stressing the great importance of the history in knee injuries, and he particularly condemned the common practice of applying a plaster to an injured knee before an accurate diagnosis had been made. He first discussed diagnosis of acute ligamentous injury, which he thought was best managed by aspiration of the knee, examination under anaesthetic if necessary and a period of rest in bed, with a pressure bandage and quadriceps exercises.

He then discussed the instances in which the anterior cruciate ligament could be torn, sometimes by a severe valgus strain which tore the medial ligament first, but much more commonly by the injury which split the medial cartilage in bucket-handle fashion. He stated that one in four such tears of the medial cartilage was associated with rupture of the anterior cruciate ligament, and gave an interesting account of how this would come about. He thought that this rupture could occur after an interval, and it was thus important to be sure that the medial cartilage was not torn and displaced before the patient was allowed to walk. He advocated early meniscectomy if one was certain that the medial cartilage was torn in this way.

Mr Smillie then discussed recurrent subluxation of the patella and recalled that this was often misdiagnosed as a torn medial cartilage, especially in women. There were four points that helped the surgeon in making a correct diagnosis: 1) bearing in mind this possibility, particularly in women; 2) discomfort when the patella is pushed laterally over the femoral condyle; 3) selective wasting of the medial part of the quadriceps muscle; and 4) demonstration of the osteochondral fracture at the edge of the patella in a skyline radiograph. He thought that the transplant medially of the ligamentum patellae gave good results, provided it was done after growth had stopped and provided the quadriceps was not lengthened too far. At a later stage he removed the osteochondral fragment. He did not like the operation of excision of the patella.

Mr A. McDougall stressed the importance of avoiding the branch of the saphenous nerve in meniscectomy, and stated that he removed only the displaced portion in dealing with a bucket-handle tear of the medial cartilage.

In further discussion the unusual nature of knee injuries in Bantu natives was discussed, and many interesting points were brought out concerning the nature and management of haemarthrosis, and the management of recurrent subluxation of the patella in younger children. *Mr Smillie* concluded by warning surgeons against using cartilage knives that bore his name but had little resemblance to the knives he originally designed.

Epiphysial Retardation By Stapling

Experience of seventy-seven cases—*Mr K. E. Guest* spoke of his experiences with stapling for arrest of leg growth. He had studied seventy-seven cases, mostly of poliomyelitis. In forty such cases he had had twenty-seven good results. Among his bad results were eight in which the operation had been done under the age of nine. He emphasised the importance of accurate technique: the staples should be placed outside the periosteum and they should be examined carefully before use for any weakness, particularly at their corners. He had had trouble from extrusion and breakage, but these complications did not seem to worsen the results. Results had been unsatisfactory in cases of shortening from tuberculosis of the hip or knee. *Mr R. Barnes* stressed the importance of accurate prediction of growth in timing the operation, and made a plea for the Phemister operation, particularly at the upper end of the tibia. It was agreed that some modification of the original Blount staple, giving it stronger angles, might reduce the imperfect results from extrusion and breakage.

Vascular Lesions in Orthopaedics

Volkmann's ischaemic contracture—*Mr D. Ll. Griffiths* (Manchester) pointed out that this was not the ideal name, for ischaemia sometimes involved many other tissues beside muscle. He reviewed fifty-five cases, forty-four complicating closed injuries and eleven complicating open wounds. Of the closed injuries, forty-one occurred in the upper limb, and a high proportion occurred in children under ten. One was caused by a crush, twenty were caused by supracondylar fractures of the humerus and five by other fractures or dislocations about the elbow; thirteen occurred after fractures of both bones of the forearm. He believed that the main causative factor was mechanical stretching of the artery, either at the time of the injury or at the hands of the surgeon. He thought the diminished incidence of Volkmann's ischaemia in the upper limb was accounted for by improved methods of reduction of fractures, and in particular by the abandonment of traction on the elbow in extension and of completion of greenstick fractures of both bones of the forearm. He did not think that reflex spasm played any part in the causation. He did not think that a tight plaster was the cause of Volkmann's ischaemic contracture. He thought that an increasing number of cases were being encountered in the lower limb from injury to the popliteal artery or posterior tibial artery by a fractured tibia. In most cases the damage occurred at the time of the accident, but he mentioned one case in which the stretch was attributed to repeated attempts to correct the fracture by skeletal traction.

He discussed the management of cases encountered possibly seven, eight or nine hours after the onset. Systematic blood pressure should be restored; the blocked artery must be explored, and (contrary to an opinion previously expressed) he believed that this should be done before a deliberate attempt at closed manipulation of the fracture. Before exploration arteriographs should be obtained to show the extent of the block. At the operation, any obstruction to the vessel should be removed, and only if the damage to the vessel was obvious and severe should the damaged portion be resected. This would be done not with the intention of relieving spasm, but in order to avoid consecutive thrombosis. An artery showing spasm only should not be resected; it should be treated with a local application of 2·5 per cent papaverine solution. Sympathectomy would not prevent Volkmann's contracture, but it should be done for the sake of the skin.

In cases seen later, he believed that splinting was powerless to prevent the full development of the contracture. He endorsed Seddon's description of an ellipsoid zone of muscle necrosis in the middle of the forearm, and he recommended excision of the infarct. There was some reason to believe that excision of the infarct at an early stage prevented the spread of the necrosis. He pointed out the extent of recovery, both in nerve and muscle, that could take place after a number of years. A forearm explored thirteen years after the event showed normal nerves and muscle, the only abnormality of which was that it was short. The problem of retaining the length of a muscle shortened by Volkmann's ischaemic contracture was insoluble.

Medical aspects—*Dr R. L. Richards* discussed the medical aspects of vascular lesions as they might present themselves to the orthopaedic surgeon. He reviewed twenty-four patients from his vascular clinic who had also attended the orthopaedic clinic with the same complaint. Of eight patients with pain in the proximal part of the lower limb, the pain appeared to be of orthopaedic origin in five and of vascular origin in three. He illustrated a case of aortic saddle block, and emphasised the simple " reactive hyperaemia " test as evidence of peripheral vascular inadequacy. The limb might have a vascular defect yet appear entirely normal, with normal peripheral pulses. In seven cases the presenting symptoms suggested claudication in the calf. In three of these the symptoms were in fact due to sciatica from a lumbar disc. Four patients attending both the vascular and orthopaedic clinics had complained of pain in the foot: in three there was an orthopaedic cause, but one with " metatarsalgia " had thromboangiitis obliterans. Of two patients attending both clinics for upper limb pain the cause was vascular in one and orthopaedic in the other.

Venous thrombosis—*Mr R. B. Wright* recognised three types of venous thrombosis in the lower limb. The first was spontaneous thrombosis occurring in varicose veins. The second was superficial thrombophlebitis; the treatment for this was not to put the patient to rest, but to support the affected area with a pad and strapping, and to keep the patient up and about. The third was deep vein thrombosis; intimal damage, stasis and increased tendency to clotting all predisposed to this after orthopaedic procedures or fractures.

Phlebothrombosis occurred in two forms: 1) traumatic (for example—spontaneous thrombosis of axillary veins, and that occurring in the calf veins of athletes); and 2) " silent " (this may present occasionally as a fatal pulmonary embolism). As aids to early diagnosis he mentioned Allen's sign, Homan's sign, a low-grade pyrexia after operation, a feeling of foreboding in the patient, and a feeling of tightness in the calf. In a suspected case treatment must be instituted at once; it should consist in heparin given intravenously, with exercises and elevation.

Mr A. R. Parkes agreed with almost everything that Mr Griffiths had said, and with the thesis that most cases of Volkmann's contracture were due to arterial damage. He believed, however, that in some cases ischaemia in muscle and nerve after injury was caused by tension in the deep fascial compartment of the limb. He suggested that it was rational to attempt treatment initially by the application of a sphygmomanometer cuff over the limb, at a pressure of 70 millimetres of mercury. Venous blood barred from the easy superficial route might now pass through the deep compartment at slightly higher pressure. He described a case in which by this method he had produced almost immediate improvement in the nerve lesion, the lesion returning with the cuff's removal and passing off again with the cuff reinflated to 70 millimetres of mercury. He believed that he had thus avoided the necessity of opening up the deep fascia and producing a bulging wound in the forearm with all its difficult features.

In further discussion there was general agreement that heparin was to be preferred to any oral anticoagulant as the initial treatment for phlebothrombosis. *Mr Griffiths* would not accept that Volkmann's ischaemia complicating fractures in childhood was likely to be caused by anything except arterial damage.

Bone Tumours

Osteoclastoma and its variants—*Mr Roland Barnes* and *Dr Mary Catto* stressed the importance of accurate diagnosis and insisted that this could not be made without a study of a pathological specimen. They discussed osteoclastoma, aneurysmal bone cyst, benign chondroblastoma, chondromyxoid fibroma, and non-osteogenic fibroma. Although there were differences in the site of these lesions, and indeed in behaviour, the most important difference was histological, and Dr Catto stressed that an osteoclastoma with a large number of giant cells was very vascular, contained fibrous tissue but no collagen, and its stromal cells were plump and ovoid. It was a tumour that did not form bone. The histology of the other four lesions mentioned differed in important ways from this lesion. *Mr Barnes* stated that, when the four variants were excluded, the osteoclastoma was a serious lesion, with a recurrence rate as high as one in three after operation.

Multiple myeloma—*Dr A. Goldberg* gave an account of multiple myeloma, stressing its diagnostic features. He showed that the protein in the blood was an abnormal constituent.

Synovial tumours—*Mr J. T. Marcroft* analysed the difficult subject of synovial tumours, of which he had had a considerable experience. He described the diagnosis and clinical features of malignant synovioma, and described the folds of synovial tissues and pseudo-capsule which were characteristic features.

Discussion—A plea was made for accurate diagnosis of bone lesions, which could in many cases be reached only after examination of a large piece of tumour. There was little confidence in aspiration biopsy. A plea was made for the establishment of special centres for the full documentation of osteoclastoma and its variants, and praise was given to the pioneer work of Jaffe in the study of the important variants. The origin of the tumours was discussed, but there was little evidence to prove or disprove the transmutation of connective-tissue cells.

Reconstructive Surgery of the Hand

Methods of obtaining skin cover after injuries to the hand—*Mr Thomas Gibson* stressed the importance of primary closure as the first essential in the treatment of hand injuries. In cases of partial loss of a digit, the decision between terminalisation and flap-graft cover must be decided on individual merits, bearing in mind the capacity of youth for adaptation. The psychological background of the patient and the function demanded would influence the decision in plastic repair. He discussed three types of technique for skin replacement: 1) free grafts; 2) local flap grafts; and 3) distant flap grafts. Free grafts took well on any surface except tendon, cartilage, and bone, and often regained

better innervation and stability than bulky flaps. Free grafts were preferable in the palm of the hand, and were used for large areas of skin loss in " degloving " injuries. Degloved skin was often devitalised by loss of blood supply, and by the initial trauma to the skin itself. Non-viable and doubtfully viable skin should be excised. A useful test was the flushing obtained in the degloved skin on release of the tourniquet. Free skin grafts were unsatisfactory on finger tips where bare bone was exposed.

Three types of local pedicle grafts were described: 1) the cross-finger graft from the back of the adjacent digit; 2) the thenar flap, which was most suitable for a long middle finger; and 3) a lateral flap graft from the side of the index finger for a thumb defect. The cross-finger method was useful for fingers other than the long middle finger.

The transference of distant flaps from abdomen and chest might be complicated by shoulder stiffness. Such grafts were more suitable for the back of the hand than for the palm. This type of graft was often too fat and bulky for fingers, and its sensibility was poor. He described a method of treatment for " degloved " finger in which the damaged segment was amputated and the intact bone, joint and nail-bed segment were buried in an abdominal flap, with later transfer back to the finger in a pedicle. In one case some joint movement had been retained and the nail grew again in one of the fingers.

Some useful tendon transplants—*Mr A. R. Parkes* enumerated the requirements for successful tendon transplants as: 1) a motor unit which was active and of adequate power; 2) re-routing should be on anatomical planes, between the superficial and the deep fascia; 3) the transplant route should be in as straight a line as possible between origin and insertion; 4) correct tension after suture; the transplant was often left too loose. He had had most success with transplant of synergistic muscles, but was not certain that this was obligatory. He described the standard transplants for radial nerve palsy, and said that the converse transplant of the radial wrist extensor to the finger flexors also gave good results. In both of these transplants loss of wrist movements impaired the final result, because the motor units had a relatively short excursion, and he emphasised the importance of leaving an intact wrist flexor in carrying out the transplant for radial nerve palsy.

In ulnar claw hand, he discussed the Bunnell sublimis transplant, and thought that this might act as a check ligament rather than an active muscle effect. He employed a similar technique to fix the proximal end of the sublimis tendons to the transverse carpal ligament as a tenodesis, with satisfactory results, and quoted Professor Paul Brand.

Illustrative films—Two ciné films loaned by *Professor Paul Brand* (Vellore) were shown, to illustrate his new technique of tendon suturing. A film by *Mr Benny Rank* (Melbourne) was also shown, demonstrating his technique of free tendon grafting for divided finger flexors, with some excellent results.

Congenital absence of the radius—*Mr T. H. Norton* said that the disabilities complained of were: 1) poor function (to which the patient might become remarkably well adapted), and 2) deformity (which was often a major complaint). Associated soft-tissue abnormalities often included absence of the muscles that normally arose from the radius, and absence or dysplasia of carpal bones. The vessels and nerves of the limb might also be abnormal or deficient. These factors might make poor function irremediable. The club hand deformity could often be improved, but considerable care was required in selection of cases: those with gross deformity and complete absence of fingers, and those with associated abnormalities such as cardiac disease or spina bifida (occurring in 20 per cent), should be excluded. The objects of treatment were: 1) correction of deformity; 2) stabilisation of the carpus; and 3) reinforcement of muscle power. He illustrated the steps in treatment by describing the case of a boy of fifteen. The tight skin on the radial side of the wrist was replaced by a full-thickness pedicle skin graft, and at the same time the deep fascial band on the side of the contracture was divided. This step was followed by skeletal traction by a Kirschner wire through the metacarpal heads, with Steinmann's pin counter-traction through the olecranon, for six weeks. Good correction was obtained, and the curvature of the ulna was corrected by osteotomy, with immobilisation by fixation pins and cross-bar. Stabilisation of the carpus was the next problem: after reviewing the recorded methods, he favoured a strut graft from the upper end of the fibula, fixed in " Y " fashion to the ulna. In one recorded case the graft had continued to grow, but in most cases overgrowth of the ulna created a later problem.

The missing thumb—*Mr W. F. White* compared the thumb to one jaw of a vice, of which the four fingers constituted the other jaw. Loss of the thumb was only equalled in disability by loss of all the fingers. Essential requirements in satisfactory reconstruction were adequate sensation, stability and strength, and a satisfactorily opposed position. In pollicisation of the index finger it was necessary to place the digit more ventrally to oppose the mid-finger. A less necessary, but still important consideration, was that the replacement should look like a thumb.

He reviewed the methods of replacing a missing thumb. Phalangisation of the remaining first metacarpal by deepening the interdigital cleft gave reasonably good results, but was best when part of the proximal phalanx had also been preserved. A thumb remodelled by bone pegs and abdominal pedicle flap grafts often remained unserviceable through loss of sensation and instability of the skin on the top. Transplants of a toe or finger were mentioned, but were subject to similar criticisms. Plastic replacement by skin flap from the thenar elements in the " cocked-hat " manner was sometimes more serviceable. Pollicisation of the index finger was the most useful method, and he did not consider that a normal index finger should preclude this, particularly as it carried normal pulp and sensation. He showed a film illustrating the technique and results of replacement by pollicisation of the index finger.

The Crushed Chest

General review—*Mr W. Sillar* said that from the records of 503 cases of chest and rib injury he had found twenty-seven instances in which a flail segment after injury caused paradoxical movement. Severe crushing injuries of the chest arose most often in works accidents, mining accidents and road accidents. One survey in Indiana had shown that 25 per cent of deaths from traffic accidents were due to crush injuries of the chest. A survey from the Radcliffe Infirmary, Oxford, showed an absolute as well as a relative increase in the incidence of chest injuries.

From the records of twenty-seven local cases he had found that only four patients had survived, but that five of the deaths were inevitable from concomitant head, abdominal and limb injuries. The ultimate problem in operation was the restoration of adequate lung ventilation.

Emergency management on admission included provision of an adequate airway, treatment of shock, aspiration of the bronchial secretions and saliva from the air passages, tracheostomy, relief of tension of the pneumothorax, and the closure of sucking wounds if present. Aspiration of a haemothorax might be required, but it was not so urgent. The main problem thereafter was the management of the flail segment of the thorax. Occasionally a pad and strapping had some beneficial effect in increasing tidal volume, but it should not be relied on.

Complications included surgical emphysema and traumatic asphyxia (neither of which seemed to have serious consequences), pneumothorax, and cardiac embarrassment from impaired venous return.

In considering the methods of dealing with the unstable chest wall, he stressed that each patient presented a separate individual problem, and considerable difficulty was often experienced in deciding the exact extent of the mobile segment. He described the normal mechanism of respiratory movement and diaphragmatic function. The paradoxical movement was often more pronounced on the second day, if the patient survived, as muscle spasm subsided, and progressive obstruction of the bronchi by secretions developed. He had found that the flail sternal segment was more serious and more difficult to control than a lateral segment of the thoracic cage. Wiring of the sternum and ribs to a cuirasse appeared to fail because they did not successfully straddle the whole of the damaged area. Direct traction by slings round the ribs could conveniently be employed using the bed frame developed at the Birmingham Accident Centre, but it had the disadvantage that the patient could not sit up. A method advocated by Professor Adams of Chicago might be more applicable: a hoop was fixed to a back brace, held in position by axillary and groin straps. If the rib traction was excessive, the patient was unable to breathe out. He had not found internal fixation helpful. He had seen one case in which the fractured sternum was stabilised by a vertical plate. This stopped the paradoxical movement, but the patient died on the eleventh day from coronary thrombosis.

He had made experiments with an insulated acrylic patch bonded directly to the skin with gum mastic, but had not used the method in practice. The need for tracheostomy was apparent in many cases, when there was failure to reach adequate tidal air by other means. Tracheostomy also permitted adequate bronchial toilet and aspiration of secretions. It should have a high place in the management of severe chest and head injuries. A cuffed tracheostomy tube was necessary when a respirator of the " patient-demand " type was to be employed, and it was considered wise to replace the tube daily and to deflate the cuffed tube for ten minutes every hour, to minimise the damage to the tracheal mucosa. He quoted Mr A. L. D'Abreu of Birmingham, who advocated early tracheostomy in all chest injuries with paradoxical respiration. Positive-pressure respirators always gave a rapid improvement by increasing lung ventilation. Visible improvement of such a patient under controlled anaesthesia was notable, but in a conscious patient difficulty was encountered in maintaining mechanical respiration when the patient could not breathe synchronously with the machine. " Patient-demand " respirators required a very sensitive trigger apparatus and one such machine developed by Professor Ian Donald for resuscitation of premature babies might meet these requirements.

The anaesthetist's problems—*Dr H. H. Pinkerton* dealt with the problem from an anaesthetist's point of view. He confirmed the necessity for adequate resuscitative measures, but warned

against the danger of overloading the circulation. He considered that adequate relief of pain in the early stages was achieved by repeated pethidine, by intravenous procaine, or by chlorpromazine. Lack of adequate filling pressure impaired the cardiac venous return. These patients were unable to cough, and an internal shunt of air occurred from lung to lung. The immediate emergency was met by intubation of the anaesthetised patient and followed by attempts to stabilise the mobile thoracic cage. Curarisation might be required in a conscious patient to abolish respiratory struggle against a respirator, but this was most unpleasant for the patient, and required heavy sedation to make it practicable. Valuable biochemical investigations during the management of the case included estimation of alkali reserve, blood pH, and possibly oxygen-saturation estimations. Hypoventilation led to acidosis and air hunger. Hyperventilation produced alkalisation with tetany and shallow breathing.

Discussion—*Mr Kenneth Fraser* said that these cases were often rendered doubly difficult by the presence of severe head and limb injuries. He recommended direct admission to an anaesthetic or resuscitation room where anaesthesia and intubation could be carried out as a first-aid measure. The hypercapnia consequent on the injury was often underestimated and produced cerebral congestion with marked excitability and non co-operation. As the underlying lung became atalectatic, the bronchial obstruction was progressive, and flail of the chest became more obvious. Radiographic examination, if possible with the patient sitting up, was desirable, to define the outer limits of the mobile segment. He doubted the value of strapping except as an emergency first-aid measure. In some cases, when full facilities were not available, transfixion of the overlying soft tissues by multiple pins and weight-and-pulley traction might be adequate.

Recent reports on the Morsh respirator suggested that this might be the most effective method whereby positive pressure was maintained by a non-cuffed tube, saliva and secretions being blown back by escaping air. By these methods, the patient was intentionally hyperventilated into a state of apnoea which was maintained until respiration ceased; thereafter the machine controlled respiration. This was said to be possible without undue biochemical upset.

Mr P. S. London (Birmingham) said that relief of pain alone by suitable intravenous injection might give marked improvement in the condition of a patient who had moderate paradoxical respiration, especially when the rib fractures were posterior. The amount of weight traction required was usually one to two pounds; it might have to be maintained, and should be maintained, for from ten to fourteen days. Traction by towel clips on the ribs was often easier than by encircling wires. The cardiac damage at the time of injury might be severe enough to cause subsequent death. Some discussion followed on the management of the cuffed tubes, and the risk of serious mucosal damage. This did not appear to be very serious in patients with poliomyelitis maintained sometimes for months on respirators with a cuffed tube in position.

Scoliosis

Curve patterns—*Professor J. I. P. James* (Edinburgh) stressed particularly the curve patterns in four varieties of idiopathic scoliosis. He stressed the importance of knowing the natural history, as a guide to prognosis and treatment. The degree of curvature was not so important as its situation in producing deformity. Professor James went on to discuss the results of his study of a large series of patients with paralytic scoliosis, and stated that here it was the age of onset of the paralysis which influenced the prognosis, whereas in idiopathic scoliosis the site of the primary curve was most important.

He described the entity of resolving infantile idiopathic scoliosis, which was one type of curve beginning in infancy which did not progress to severe deformity. He concluded by describing his method of treatment for the various types of curve. He thought correction and fusion of established idiopathic scoliosis was scarcely worth while, and felt that the greatest benefit of surgical fusion was in paralytic curves and those idiopathic ones which, although not severe, were certain to deteriorate in spite of conservative treatment.

Mr N. J. Blockey enlarged upon the problem presented by idiopathic infantile scoliosis, and suggested that spinal fusion at the age of three or four years might be the best treatment, provided one could reduce the curve to 25 degrees or less, though Professor James had thought that spinal fusion was unwise below the age of seven or eight.

Other Papers

Congenital dislocation of the hip—*Mr E. W. Somerville* (Oxford) described his original concept of this condition. In his view the primary lesion was a laxity of the anterior capsule; thus when the foetal hip was extended, the head could come out of the front of the socket, and gradually pass to the back where it would indent the acetabular rim. This indentation, he thought, was the down-turned limbus. The original anterior position of the femoral head caused an increase in the angle of anteversion

present in all foetal hips. Based on this concept of the pathology, he described frame reduction, arthrography, excision of the limbus, and rotation osteotomy of 70 or more degrees, a programme which took fourteen weeks. He stressed the advantage of this programme over the more classical ones, both as regards time and long-term results. He showed radiographs illustrating two new concepts: firstly progressive ossification of the cartilaginous roof of the acetabulum, which could occur in spite of radiological evidence of a sloping roof after reduction; and secondly the eccentric ossification of the capital epiphysis.

Mr A. G. M. Watt claimed adequate results from manipulation, reduction, and mobilisation of the hip in the most stable position, rather than in the full medial rotation that Mr Somerville had advised. *Mr Blockey* doubted the concept that the limbus was pushed into the acetabulum by the dislocation of the femoral head. He showed two cases in which the programme advised by Mr Somerville had been carried out, and yet the hip had subsequently dislocated. *Mr Somerville* gave his explanation of these misfortunes, and concluded by saying that he thought it a mistake to interpret the arthrograph too literally. He used it to tell him whether there was an obstruction to reduction, rather than to give information as to the exact site and disposition of that obstruction.

UNIVERSITY OF LIVERPOOL

McMURRAY MEMORIAL LECTURE

The second McMurray Memorial Lecture was given by Professor Walter P. Blount on November 7, 1958, at the New Medical School, Liverpool. Mr J. M. Leggate, Dean of the Medical School, presided and the Lecturer was introduced by Professor Bryan McFarland. Professor Blount chose as his subject the theme " Fractures in Children are Different." He began by quoting from the late Professor T. P. McMurray's writings on children's bones, in which their difference from adults' bones was emphasised. He stressed both the importance of their growth potential in overcoming deformity, and the fact that they often reacted adversely to operative intervention. He illustrated these principles by first considering fractures of the shaft of the femur. In the first year after a fracture, a child's femur would " overgrow " by half an inch if the ends had been allowed to join with overlapping. It was advisable to maintain alignment, but perfect apposition and length were not essential, and a good result could be obtained by simple skin traction. Operative interference, plating and intramedullary nailing were not necessary, and might lead to disastrous complications.

Professor Blount then considered fractures in the forearm, particularly fractures of the lower end of the radius, and again pointed out the tremendous remodelling powers of growing bone. Provided the epiphysial plate had not been damaged even 50 degrees of angulation would disappear in a young child. Again operation was liable to do harm and might lead to delayed union or non-union.

Turning to the elbow, the lecturer again pointed out the tendency for supracondylar fractures to correct deformity with growth so long as alignment was normal. He indicated that there were three elbow fractures in children which usually required operative correction: fractures of the capitulum with rotatory displacement, fractures of the medial epicondyle, especially if a fragment were displaced into the joint, and fractures of the neck of the radius with much tilting of the radial head. He emphasised the need for immediate intervention: operation at the wrong time may lead to a stiff elbow. On no account should the radial head be removed in children: disastrous shortening and dislocation of the inferior radio-ulnar joint would result.

In the subsequent discussion Professor Blount outlined the treatment of premature post-traumatic closure of the medial half of the lower tibial epiphysis (railing's fracture) and discussed the role of epiphysiodesis of the opposite limb.

DEGREE OF M.Ch.Orth.

Eleven candidates were successful in gaining this degree. They were: B. C. Bracken (Sydney, Australia); H. Berzen (Johannesburg, South Africa); S. K. Bulchandani (Bombay, India); P. H. Corkery (Cork, Ireland); C. P. Cotterill (Birmingham, England); N. Grewal (Georgetown, British Guiana); P. B. Gupta (Bombay, India); D. R. Lee (Cape Town, South Africa); A. K. Mitra (Calcutta. India); R. A. B. Vance (Sydney, Australia); and H. Weisl (Liverpool, England).

The Gold Medal in Orthopaedic Surgery was awarded to Mr B. C. Bracken. The external examiners were Mr H. Osmond-Clarke of London and Mr F. Holdsworth of Sheffield. The internal examiners were Professor Bryan McFarland, Mr Norman Roberts, Mr Eric Wardle and Mr Goronwy Thomas.

On July 4, 1958, the Honorary Degree of Master of Orthopaedic Surgery was conferred upon Sir Walter Mercer, Emeritus Professor of Orthopaedic Surgery, University of Edinburgh, and immediate Past-President of the Royal College of Surgeons of Edinburgh.

REGIONAL ORTHOPAEDIC CLUBS

NORTH-EAST METROPOLITAN REGIONAL ORTHOPAEDIC CLUB

A meeting was held at Oldchurch Hospital, Romford, on November 1, 1958. Clinical cases were presented by Mr R. A. King and Mr T. Hunter, and the discussion was under the chairmanship of Mr H. Osmond-Clarke.

Congenital absence of radius—Two examples in young children were shown. In one, a homogenous graft inserted to replace the radius had been rejected by the host tissues. It was suggested that a V-graft from the ulna should be used to prevent progressive radial deviation of the hand during growth, followed ultimately by fusion of the ulna to the carpus.

Monostotic fibrous dysplasia of the tibia—A case was shown in which extensive involvement of the whole tibial shaft had finally necessitated diaphysectomy and replacement by a massive homogenous graft. The graft was in turn affected by fibrocystic changes, and had to be removed. Fusion of the fibular shaft to the proximal and distal tibial metaphyses was followed by hypertrophy of the fibula and an excellent functional result.

Multiple metaphysial fractures in infancy (shown by courtesy of Dr T. Savage)—Skeletal survey of a premature infant, who developed pseudo-paralysis of one lower limb at two months, had revealed symmetrical metaphysial defects at the proximal ends of both humeri and femora, with periosteal new bone formation. Radiographs two years later showed normal appearances of the affected bones. Opinion was divided whether the condition was traumatic or infective.

Unusual ulnar nerve paresis—A middle-aged woman had developed weakness of the entire intrinsic musculature of her right hand. Nerve block and electromyography had demonstrated that these muscles were all innervated by the ulnar nerve, but no lesion of that nerve was found on exploration and no improvement had followed its anterior transposition at the elbow. It was suggested that this might be a scalenus anterior syndrome, associated with anomalous ulnar nerve distribution, and further exploration with division of the scalenus anterior muscle was advocated. An alternative diagnosis was isolated peripheral nerve palsy.

Injuries to the cervical spine—A group of cases demonstrating the results of dislocations and fracture-dislocations of the cervical vertebrae, with cord involvement, was reviewed. There appeared to be unanimity on the benefits of early internal fixation.

"Salvage" in paraplegia—Three patients were shown, each of whom had undergone an extensive series of soft-tissue operations. The first, with subacute combined degeneration of the cord, was able to walk with elbow crutches, and to earn his living. The second, who suffered from disseminated sclerosis, was able to walk with calipers and a walking machine. The third, also with a demyelinating disease, had had both lower limbs disarticulated at the hip joints and led a wheel-chair existence. Varying opinions were expressed on the advantages of ablating the lower limbs in otherwise hopeless cases, and the procedure found many supporters.

Complications of Paget's disease—Cases of sarcoma and of infection superimposed on Paget's disease were demonstrated, and also one showing the effect of injury, which may simulate sarcomatous change radiographically by producing great rarefaction.

Spontaneous leg length equalisation—Radiographs were shown of a boy of eight who had sustained a closed fracture of the femoral shaft which, because of the seriousness of his other injuries, had been allowed to unite with shortening of one and a half inches. Serial films over a period of five years proved that the difference in lengths of the femoral shafts had progressively diminished, the present discrepancy being only a quarter of an inch.

Hyperplastic callus after fracture in osteogenesis imperfecta (shown by courtesy of Mr W. D. Park)—A boy of two had developed clinical and radiographic signs exactly resembling sarcoma after a closed fracture of the femoral shaft. No evidence of malignancy was found in biopsy specimens.

NORTH-WEST METROPOLITAN ORTHOPAEDIC CLUB

A meeting of the North-West Metropolitan Orthopaedic Club was held at Bedford General Hospital on September 20, 1958, by kind invitation of Mr G. S. Storrs. The following members were present: G. P. Arden, J. G. Bonnin, W. Herschell, P. R. N. Kerr, R. H. Maudsley, G. H. Pearce, A. F. Rushforth, G. S. Storrs and W. Waldie.

The following were shown by Mr Storrs: Gumma of medial tibial condyle and bodies of T.12 and L.2 vertebrae; guide apparatus for Smith-Petersen nailing through a stab incision; multiple tendon transplants through transverse incisions; a fractured neck of femur in child of fourteen with avascular necrosis, treated by stainless steel prosthesis; locally malignant synovioma of hip treated by local excision, biopsy and cobalt irradiation; rickets in sisters; valgus heel treated by iliac graft; fracture of Stamm's prosthesis replaced by stainless steel Judet prosthesis; three cases of patellectomy for fracture; spondylolisthesis of L.5/S.1 treated by grafts and screw fixation; comminuted fracture of humerus treated by fibular graft; a tubular reamer for shaping fibular grafts.

Operations upon the knee—*Mr R. W. Butler* (Cambridge) gave a talk on knee surgery. Instead of a pressure bandage he advocated a firm pad over the incision and Elastoplast two-thirds round the knee with a piece above and below, then three turns of bandage, retained for twenty-four hours only. This method of dressing minimised effusion and pain.

For exploration of the outer side of the knee he used a vertical S-shaped incision and turned up a flap of fascia lata. Then through a transverse incision a capsule flap was turned down. The patient lay on his opposite side with the knee semi-flexed. At the back could be seen the lateral [fibular collateral] ligament and popliteus tendon. This was a good incision for removal of a cystic or discoid cartilage.

Degenerative lesions of the medial cartilage in men of middle age were worth excision to delay the progress of osteoarthritis.

Mr Butler thought that for recurrent dislocations of the patella the Goldthwait operation and excision of the patella gave equal results.

EAST ANGLIAN ORTHOPAEDIC CLUB

A meeting of the East Anglian Orthopaedic Club was held at the Thorpe Hall Rehabilitation Centre, Peterborough, on May 31, 1958.

Sciatica—*Mr Noel Smith* demonstrated cases of low back pain with radiation of sciatic type. He described the following unusual cases: 1) A man with an old gunshot wound with residual metallic fragment between lumbar vertebrae 3 and 4. Pain was relieved after removal of the fragment. 2) A man who had previously been diagnosed as having Hodgkin's disease and treated with corticosteroids without benefit. Radiographs showed collapse of the vertebral bodies of T.12 and L.2 and 3. Eventually the diagnosis of chronic lymphocytic leukaemia was established. 3) A woman who presented with a typical story of sciatica but showed rapid degeneration with loss of control of sphincters. An enlarged gland in the groin revealed a neoplasm and she was found to have a primary ovarian tumour. 4) A woman with pain in both legs whose radiograph showed patchy rarefaction of vertebral bodies, probably from a haemangioma. 5) A man whose radiograph showed destruction of L.5 vertebral body from a myeloma. 6) A man of seventy-two with collapse of bodies of L.2, 4 and 5 vertebrae, with developing paraplegia. The diagnosis of chondro-sarcoma was established after his death. 7) Sciatica during pregnancy. The symptoms included difficulty of micturition. Radiographs did not show any abnormality. The symptoms were relieved by physiotherapy, but a hard elastic swelling was noticed on vaginal examination. After a normal labour this was found to be a chondrosarcoma.

Malignant synovioma of the tendon of biceps—*Mr S. Kanagasbaby* showed a case of malignant synovioma of the tendon of biceps which came to light through a minor injury after which a slowly forming tumour in the upper arm was noticed.

Dermatomyositis—*Mr B. L. Phillips* showed a boy of nine with dermatomyositis. He was always tired, had blotchy skin and patches of necrosis. He was being treated with prednisone.

Monostotic fibrous dysplasia—*Mr Phillips* showed a pathological fracture of the humerus from monostotic fibrous dysplasia.

Syphilis of bone—*Mr Phillips* showed a patient with the now uncommon condition of epiphysitis of the lower end of femur and lower end of radius in a case of congenital syphilis. He pointed out that syphilis nowadays was a cause of bone disease likely to be overlooked in this country.

Fracture-dislocation of hip—*Mr J. Jennings* showed a case of dislocation of hip with fracture of the head; the fragment was fixed by a screw after reduction of the dislocation.

Swelling in femoral triangle displacing the femoral artery—*Mr Jennings* illustrated the case of a patient with a huge swelling in the femoral triangle displacing the femoral artery. This proved to be a thickened bursa connecting with hip joint.

NORTH OF SCOTLAND ORTHOPAEDIC SOCIETY

A meeting of the Society was held at Raigmore Hospital, Inverness, on November 1, 1958. The meeting opened with discussion on the techniques of spinal fusion. Mr J. F. Frew and Mr R. C. Murray showed examples of Albee grafts as a basis for argument, but many of those present favoured the Hibbs technique with supplementary bone from the bone bank. Thereafter a ward round stimulated further discussion. Those present had a combined experience of three cases of recurrent posterior dislocation of the shoulder, and they favoured repair by a bone block technique. The etiology of ulnar neuritis and the relationship of local elbow conditions with median nerve compression and cervical root irritation was debated.

IRISH ORTHOPAEDIC CLUB

A meeting of the Irish Orthopaedic Club was held at Musgrave Park Hospital, Belfast, on November 29, 1958. Mr R. J. W. Withers took the chair, and the sympathy of the members on the death of Mr Henry McAuley, a founder member of the Club, was recorded.

Mr Withers introduced four members of the Department of Anatomy, Queen's University, Belfast, who read short papers on recent research into the problems of bone growth, fracture repair and homografts.

Pelvic development and growth—*Dr T. J. Harrison* described his experimental studies in the rat. He demonstrated that the ilium migrates caudally in relation to the sacro-iliac joint, because of the tension of the superior sacro-iliac ligament. Transection of this ligament leads to failure of iliac descent and to pelvic asymmetry and eventual bony ankylosis of the sacro-iliac joint. Removal of the cristal epiphysial cartilage interferes with iliac descent as well as causing shortening of the ilium. Transection of the ilium below the sacro-iliac joint is followed by continued descent of the upper fragment, but failure of descent of the lower fragment. Dr Harrison described the results of further experiments in the rat, designed to demonstrate the effect on the development of the acetabulum and pelvis of several surgical procedures at the hip joint. Disarticulation of the hind limb led to thinning of the acetabular articular cartilage, loss of acetabular depth, diminution of growth of the affected side of the pelvis, and a curve of the innominate bone convex to the normal side. High femoral amputation again led to slight pelvic curvature and some thickening of the acetabular floor. These results also followed excision of the head and neck of the femur. He concluded that for normal pelvic growth the femoral head must be in the acetabulum.

Fracture repair—*Mr H. C. Mulholland* described experimental work in rats designed to determine whether there was a critical size of gap across which bone union would not occur. In a series of experiments he demonstrated that bony union invariably occurred when the gap was 0·75 millimetres or less; that fibrous union occurred with a gap of 1 millimetre; and that a gap of 1·5 millimetres resulted in fibrous union with soft-tissue interposition. When a polythene tube was threaded over the ends of the fragments, however, bony union took place in the presence of a gap of 1·5 millimetres. *Mr J. T. McDaniel* concluded from a series of experiments in rats that the greatest periosteal osteogenic activity occurs in the first four days after fracture, the subsequent process being one of transformation of tissues already present rather than of further periosteal proliferation.

Marrow homografts—*Dr J. B. Bridges* discussed experiments in mice in which the lethal effects of radiation had been prevented by injection of saline suspensions of bone marrow. He considered that the injected marrow cells stimulated regeneration of the host bone marrow and lymphatic tissue, and were able to proliferate and produce functioning blood-producing cells. He discussed the possible application of these findings to the treatment of leukaemia and in kidney transplantation.

Anterior spinal drainage and fusion—*Mr N. S. Martin* reviewed fifteen cases, with one death, giving as the principal indication the presence of instability of the spine at the level of the disease, with or without paraplegia. He demonstrated the transpleural approach to the mid-thoracic region, and the more difficult thoraco-lumbar approach. He introduced several very convincing patients, two of whom had had previous lateral rhachotomy without permanent healing.

Tibial lengthening—*Mr G. W. Baker* reviewed twenty-two cases, the patients ranging in age from nine to eighteen. The shortening in most cases had followed poliomyelitis. In all cases the intended lengthening was achieved without difficulty, the greatest gain being three inches. The only troublesome complication was anterior bowing of the tibia, which led to non-union in one case; but Mr Baker considered that by a minor alteration to the apparatus this could now be avoided with certainty. The average time from operation to the resumption of full activity was ten and a half months.

Unusual ankle injury—*Mr J. B. Pyper* had collected twenty cases of a fracture of what might be called the lateral malleolus of the tibia. These cases had been seen in the fracture clinic of the Royal Victoria

Hospital in the past seven years, and the injury, though not described in the standard text-books, seemed therefore not uncommon. The patients were all young, being aged thirteen to nineteen years. Mr Pyper concluded from his survey that manipulative reduction produced better function than open operation.

Primary malignant bone tumours—*Mr R. J. W. Withers* discussed thirty-nine cases seen between 1943 and 1953. Fourteen of the patients were still alive at least five years after diagnosis. Three out of nine patients with osteogenic sarcoma survived, with their limbs intact, after treatment by radiotherapy. Two patients out of thirteen with chondrosarcoma were alive, treatment being by amputation. One patient out of eight with fibrosarcoma survived after treatment by local excision and radiotherapy. Of nine patients with round-cell sarcoma eight were alive, treatment being by radiotherapy. Mr Withers concluded that a chondroma of a long bone might become malignant through inefficient surgery; that except in cases of chondrosarcoma amputation was usually only palliative; that local excision and radiotherapy made the best of a bad job in fibrosarcoma; that the only survivors of osteogenic sarcoma were those treated by radiotherapy, without amputation; and that in general, radiotherapy gave the best hope of success.

FRANCE

FRENCH ORTHOPAEDIC SOCIETY

A meeting of the French Orthopaedic Society was held in Paris from October 7 to 10, 1958. The two main topics for discussion were: 1) fractures of the thoraco-lumbar spine; and 2) prosthetic replacement after amputation of the upper limb. The openers for the first symposium were M. P. Decoulx (Lille) and M. G. Rieunau (Toulouse), and for the second M. P. Maurer (Paris) and M. J. Houssa (Brussels). One day of the meeting was devoted to operation sessions at various hospitals in Paris. During the meeting Professor J. Creyssel (Lyons) handed over the office of President to his successor, Professor R. Merle d'Aubigné (Paris). The other officers are: Vice-presidents, Professor L. Pouyanne and Dr P. Petit; secretary, Dr P. Lance; assistant secretary, Dr M. Postel; treasurer, Dr J. Judet.

REVUE D'ORTHOPEDIE

Dr A. Mouchet has resigned from the office of Editor, and the Executive Committee have appointed M. M. Fèvre and Professor Merle d'Aubigné as co-editors, with the assistance of M. R. Meary, M. P. Queneau and M. G. de Mourgues.

ITALY

ITALIAN SOCIETY OF ORTHOPAEDICS AND TRAUMATOLOGY: FORTY-THIRD CONGRESS

The Forty-third Congress of the Italian Society of Orthopaedics and Traumatology was held in Padua from October 19 to 21, 1958, under the presidency of Professor C. Casuccio. A number of foreign visitors were welcomed, including Professor M. Hackenbroch (Cologne), Dr M. Guilleminet (Lyons), Dr M. Bastos Ansart (Madrid), Mr H. Jackson Burrows (London), Mr E. A. Nicoll (Mansfield), Dr J. Judet (Paris), Dr L. Böhler (Vienna), Dr J. Zaremba (Warsaw).

The main topic for discussion was bone grafting, and the following papers were included in the symposium: 1) Bone grafts—general considerations and biology—F. Vigliani (Padua); 2) Autogenous bone grafts in man—G. Stringa (Florence); 3) Homogenous bone grafts in man—S. Mastragostino (Genoa); 4) Heterogenous bone grafts in man—E. Agrifoglio (Genoa).

ANNOUNCEMENTS

BRITISH ORTHOPAEDIC ASSOCIATION: SPRING MEETING 1959

The spring meeting of the British Orthopaedic Association will take place from April 29 to May 2 in Torquay and Exeter. The headquarters hotel will be the Imperial Hotel, Torquay. Members and visitors will assemble in the late afternoon of April 29. It is expected that nearly a hundred members of the French and Belgian Orthopaedic Societies, many with their wives, will attend as guests of the Association. The presidents of the two visiting societies are Professor R. Merle d'Aubigné (Paris) and Professor P. Lorthioir (Brussels). Professor Paul Colonna (Philadelphia) will present a review of his trochanteric arthroplasty operation. Scientific film sessions will be held on the evenings of April 29 and 30.

Scientific papers will be presented at the Marine Spa Ballroom on April 30 and on the morning of May 2. On May 1 the morning will be spent at Exeter at the Princess Elizabeth Orthopaedic

Hospital. In the afternoon the President and Mrs Capener will hold a garden party at Haldon Grange. In the evening the conference banquet will be at the Imperial Hotel, Torquay. On Saturday afternoon a special visit will be arranged to Exeter Cathedral and Guildhall. In the Chapter House there will be an exhibition of historic documents and treasures from the medical libraries.

During the meeting there will be symposia on adolescent coxa vara and on cerebral palsy, and among the papers selected emphasis will be given to the orthopaedic problems of trauma.

FRENCH ORTHOPAEDIC SOCIETY

A meeting of the French Orthopaedic Society will be held at the Hôpital des Enfants-Malades in Paris on January 24, 1959. The subject for discussion will be " Osteotomy in the treatment of osteoarthritis of the hip."

A meeting with the British Orthopaedic Association will be held from April 29 to May 2, 1959, in Torquay and Exeter.

The autumn meeting of the Society will be held in Paris from October 6 to 10, 1959, under the presidency of Professor R. Merle d'Aubigné. At this meeting the new buildings of the orthopaedic department of the Hôpital Cochin will be formally opened. Visitors from Britain will be welcome. The main topics for discussion will be: 1) treatment of back pain; and 2) non-union of fractures of the scaphoid bone.

INTERNATIONAL SOCIETY OF ORTHOPAEDIC SURGERY AND TRAUMATOLOGY

The next meeting of the International Society of Orthopaedic Surgery and Traumatology will be held in New York City on September 4–10, 1960. The headquarters hotel will be the Hotel Astor. Suitable and reasonable accommodation will be available at the Astor and in nearby hotels.

The broad subjects for discussion at this meeting will be:

1. Congenital acetabular dysplasia.
2. Osteogenesis and treatment of delayed union and non-union in long bones.
3. Teaching and training in orthopaedic surgery and traumatology and the organisation of hospital services.

There will be an associated audio-visual programme as well as commercial and scientific exhibits.

The meeting is open to all interested members of the medical profession. After the meeting tours to nearby orthopaedic centres will be arranged.

Travel to the United States may be arranged through the American Express Company. Inquiries regarding accommodation should be made to the Hotel Astor, New York City.

Book Reviews

POLYMYOSITIS. By John N. WALTON, M.D., M.R.C.P., First Assistant in Neurology, King's College, University of Durham, in the Royal Victoria Infirmary, Newcastle upon Tyne; and Raymond D. ADAMS, M.D., Bullard Professor of Neuropathology, Harvard University. $8\frac{3}{4} \times 6$ in. Pp. x+270, with 47 figures (6 in colour), 9 tables. Index. 1958. Edinburgh and London: E. & S. Livingstone Ltd. Price 32s. 6d.

Patients suffering from the various forms of myopathy seek the help of the general practitioner, general physician, orthopaedic surgeon, paediatrician, neurologist and others. A book about the myopathies has therefore a wide potential appeal. Muscular dystrophy is not the only form of myopathy and in recent years increasing attention has been directed towards myopathies due to polymyositis in its many forms. About them an enormous literature has accumulated under such descriptive terms as dermatomyositis, polymyositis, neuromyositis, myositis fibrosa, myositis ossificans, calcinosis, menopausal muscular dystrophy, myopathy of later life, myasthenic myopathy and carcinomatous myopathy. It has also come to be realised that polymyositis sometimes mimics muscular dystrophy very closely. Since polymyositis differs from muscular dystrophy by carrying a natural remission rate and being amenable to treatment, it is of first importance to make the distinction.

This book, based on personal experience of forty cases and an exhaustive study and criticism of the literature, clarifies the relationship between the many recorded forms of polymyositis. Besides describing the clinical features it also points the way to differential diagnosis from chronic disorder such as muscular dystrophy and myasthenia gravis and from acute conditions such as polyneuritis and acute idiopathic myoglobinuria. In the authors' view polymyositis is not a single disease entity but probably often a hypersensitivity or allergic response of the tissues involved, which relates it, etiologically, to other diseases of the "collagen" group. The natural history, histology, electrodiagnostic and biochemical findings in polymyositis are all discussed.

This is an important and interesting book by two well known neurologists from either side of the Atlantic.—Paul SANDIFER.

TETANIE. By Doz. Dr Hans JESSERER. Assistant der I. Medizinischen Universitätsklinik in Wien. $9\frac{1}{2} \times 7$ in. Pp. xii+191, with 52 illustrations. Index. 1958. Stuttgart: Georg Thieme Verlag. Price DM 29.70.

With so much clinical literature nowadays consisting of graphs and tables manufactured from laboratory data there is something refreshingly old-fashioned about this well produced monograph. To observe and to classify rather than to quantitate has been the author's aim. His experience is based on a series of 680 cases of tetany seen in the course of the last twelve years and on a review of the clinical literature of the past century. After a detailed description of the clinical manifestations of tetany, the author provides a comprehensive classification of those conditions with which it may be associated.

There are two main subdivisions, the hypo- and the normo-calcaemic. It must be relatively rare for cases of hypocalcaemia to present in the form of tetany—in most instances the underlying clinical condition (for example, parathyroid insufficiency or defective absorption of calcium by the gut) will have been diagnosed already and the occurrence of tetany should serve only as a reproach to the clinician for the inadequacy of his treatment. The sections of the monograph covering this group of conditions could with advantage have been considerably shortened. Tetany associated with a normal serum calcium is a much more difficult diagnostic problem. In some instances the etiology is obvious—a metabolic or a respiratory alkalosis, or disease of the central nervous system. There are other cases in which the attacks are precipitated by some minor procedure such as a hypodermic injection or the passage of a Ryle's tube or by the exhibition of various drugs (adrenalin, morphia, caffein and nicotine are amongst those listed). Most normo-calcaemic tetanies, however, are idiopathic and not symptomatic and their differentiation from epileptic or hysterical manifestations remains a difficult problem which merits the exhaustive discussion given in this book.—P. G. WALKER.

THE EARLY STAGES OF OSTEOGENESIS IN TISSUE CULTURE. A morphologic and biochemical study. By John SEVASTIKOGLOU. 9×6 in. Pp. 94, with 49 figures and 6 tables. 1958. Copenhagen: Ejnar Munksgaard. Acta Orthopaedica Scandinavica. Supplementum No. XXXIII. Price Dan. kr. 25.00.

In Sweden it is traditional for students, before graduating, to carry out some research—and the best is then published. From Karolinska Institutet there have been many such publications of excellent work, and this monograph maintains their tradition. There are described here the results of a morphological and biochemical study of early osteogenesis in embryonic epiphysial cartilage of the chick *in vivo* and during tissue culture *in vitro*. The problems of the origin of osteoblasts in endochondral ossification, of the function of alkaline and acid phosphatases, and of the origin and formation of collagen are well poised, with a good bibliography.

The author emphasises how rarely embryonic epiphysial cartilage has been used in the past to study osteogenetic potency, and the reasons for this should be appreciated. The explants in these experiments consisted mainly of the flattened early chondrocytes and the hypertrophic degenerated chondrocytes from the middle zone of the epiphysis. These cells have differentiated, are "determined," and are capable only of giving rise to one kind of tissue (Wilton 1937) as an all-or-none phenomenon (Needham 1952) as long as their nutritional requirements are maintained. However, the cells from this zone of the epiphysial cartilage have been shown to be most vulnerable to any change in their nutrition or environment. Such varied factors as the administration of oestrogens in excessive dosages, of cortisone, and of radiation from radiophosphorus ions, have all been described as producing abnormalities in these cells. The 30 per cent incidence or more of calcification in the areas of " degeneration " cells and in a few of the " differentiating " culture cells, supports this concept of vulnerability, especially as the author considered that it was a true reaction of degeneration with calcification by crystallisation. In this study a good definition is given of the composition of the explants, but, in spite of careful dissection, contamination by remnants of perichondrium was seen in 94·6 per cent of all controls. The perichondrium consists of cells arising in the juxta-epiphysial zone and these are known to have great osteogenetic potency. Because of this, there was difficulty in defining the origin of the cells participating in the growth and differentiation of the explants. There was also difficulty in interpreting whether the " observed histological changes in the cultures was evidence of the formation of pre-osseous tissue."

By using both homologous (promoting) and heterologous (inhibiting) media, with or without the addition of embryonic extract, it was possible to divide the cultures into two major groups. In the first group ("differentiating") there was a higher incidence of growth and differentiation, whereas in the second ("degenerating") " the incidence of growth was poor after an initial short-lived proliferation." Also in this group " practically no osteogenetic layer developed nor was any pre-osseous tissue formed, and calcium deposition occurred frequently." The addition of either fresh (promoting) or filtered (inhibiting) embryonic extract augmented this division into these groups. This effect was produced by " some alteration in some component of high molecular weight," rather than by any change produced by the filtration process in the vitamin C content of the extract.

In the second part of the work accurate biochemical studies of both *in vitro* and *in vivo* material were carried out. Alkaline phosphatase, acid phosphatase and phenol-sulphatase activities; proline content for collagen; galactosamine and glucosamine levels, as well as the quantitative incorporation of radioactive sulphur by the sulphated mucopolysaccharides, were all measured. Elevation of their normal values confirmed the morphological observation that growth activity was taking place in cultures exhibiting differentiation, but not in the others. The estimation of the uptake of radioactive sulphur by the differentiating cells showed initially a significant uptake which disappeared within a week of culture *in vitro* and within sixteen days *in vivo*. The author's suggestion that " chondroitin sulphate is of little, if any, significance in osteogenesis " is regarded so far as not yet proven.

In reviewing this monograph, the classical work by Dr Honor Fell (1928) on the tissue culture *in vitro* of skeletal tissues, was read again. This work has never been surpassed for its quality of morphological description or reasoning, and one considers that further advances in our understanding of osteogenesis will come only from such biochemical studies as described here by Dr Sevastikoglou.

Although this work will be of most interest to those participating in this field, it will also serve to others as an example of a well planned and recorded biological experiment.—Robert B. DUTHIE.

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NEEDHAM, A. E. (1952): Regeneration and Wound-healing, p. 70. London: Methuen & Co. Ltd.

WILTON, A. (1937): Tissue Reactions in Bone and Dentine. London: Henry Kimpton.

CHIRURGIE INFANTILE D'URGENCE. By Marcel FÈVRE, Professor de Clinique Chirurgicale Infantile à la Faculté de Médecine de Paris, Chirurgien de l'Hôpital des Enfants-Malades; with the collaboration of Denys PELLERIN, Chirurgien Assistant des Hôpitaux de Paris. Second edition. $10\frac{3}{4} \times 7\frac{1}{2}$ in. Pp. viii+718, with 201 figures. Index. 1958. Paris: Masson et Cie. Price 8,000 fr.

The first edition of this work, based on practical experience gained in the famous Hôpital des Enfants-Malades, appeared in 1933. The war contributed largely to the delay in appearance of this the second edition. It now runs to seven hundred pages, all of them written with the clarity for which French medical literature is notable.

The British reader, accustomed to the great number of vivid illustrations employed by Hamilton Bailey and McNeill Love to illumine such works as *Emergency Surgery* and *Physical Signs in Clinical Surgery*, might expect to find that something akin had been done in the French manner for the acute surgery of children; he would be disappointed; there is not a single block in colour, and there are stretches of solid text from ten to thirty pages long.

In the section on fractures the standard methods of conservative treatment are mentioned, but the radiographs tend to accent operative methods of treatment such as the use of: Kirschner wire to fix the head of the radius, a supracondylar fracture, a capitulum and an ulna; the *fixateur externe* of Ombrédanne applied to a radius; and a Küntscher nail for a transverse fracture of the middle of the femur.

The omission of any precise references to the literature is something that could be easily corrected. Taken as a whole, this book leaves an impression that with little further effort it could do much fuller justice to the vast experience and authority of its principal author.—K. I. NISSEN.

A GUIDE TO THE EVALUATION OF PERMANENT IMPAIRMENT OF THE EXTREMITIES AND BACK. By the Committee on Medical Rating of Physical Impairment. Special Edition, The Journal of the American Medical Association. 11×8 in. Pp. 112, with many figures and tables. February 15, 1958. Chicago: American Medical Association. A limited number of complimentary copies available.

In 1956 the American Medical Association set up a Committee to establish guides for the "Medical Rating of Physical Impairment." This is its first publication, dealing with the upper and lower extremities and the back.

The problem in assessing this book is that, although the Committee has done its work well and expressed its ideas clearly, many clinicians would feel that the task set to the Committee was an impossible one, for it presumes that physical impairment can be reduced to a standard formula. Those who think that it cannot will judge the publication accordingly, however well the Committee has worked.

To make the task possible a clear distinction was made between "impairment," which is defined as a medical condition to be evaluated by doctors; and "disability," which includes also non-medical factors such as age, sex, education, and economic and social environment. The Committee concerned itself only with "impairment," and restricted itself still further to "permanent impairment," which is "any anatomical or functional abnormality or loss after maximal medical rehabilitation." With the problem simplified in this way, the assessment is based on measurements of restriction of joint range, ankylosis and amputation. The methods of measurement are clearly outlined and illustrated with diagrams, and mainly conform with standard practice in this country. The goniometer is used extensively. Each measurement can then be translated into "impairment" from the many tables. Using the knee as an example, amputation at the joint represents 90 per cent impairment of the lower extremity, and ankylosis at 40 degrees from full extension represents 63 per cent impairment; these figures can then be calculated as 36 per cent and 25 per cent impairment of the whole man. There are also tables for calculating the impairment from two or more involved sites; and tables giving the impairment from certain fractures. Thus three fractured vertebrae combine to give the following impairment of the spine:

First vertebra—Fractured body and arch	16 per cent
Second vertebra—Fractured arch	3 „
Third vertebra—Fractured body	13 „
Total impairment of the spine	30 per cent
Impairment of the whole man	18 „

This type of assessment can have a place only in administrative problems, such as the assessment of compensation claims, where an arbitrary scale based on objective data may be essential. But, even for this purpose, it would have to be widely adopted to give it real meaning in this country. In the field of rehabilitation there is no place for this method, because it is too narrow in its approach. Assessment for this purpose is more complicated and essentially related to skilled functions. All our experience is that patients must be tested on stairs, in the kitchen or at the turret lathe; and that measurements of strength of individual muscles and range of individual joints are inadequate. It is strange to see administration and rehabilitation moving in opposite directions, but presumably it is essential.—D. A. BREWERTON.

REHABILITATION. Vol. 1. No. 1. Section XIX. July 1958. Amsterdam and New York: Excerpta Medica. Price $15.00 per year (twelve monthly issues).

This is a new abstract publication of the Excerpta Medica Foundation concentrating on Rehabilitation, which is defined as the ultimate restoration of the disabled person to his maximum capacity, physical, emotional, social and vocational. From such a wide definition, it follows that the field covered must be very extensive. The contents include articles on the history and philosophy of rehabilitation. There are sections on research statistics and anatomy, physiology and pathology, and it touches practically all branches of medicine, giving particular attention to orthopaedic surgery and the various aspects of the orthopaedic surgeon's work. There is a section on " Daily Living," with sections on Physical Medicine and on Social Medicine. In short, this is a publication which should have something for all who are concerned with getting disabled persons back to work. It brings together good abstracts of articles on many, if not all, aspects of the problem. Though it adds one more to the journals on this subject, the addition is a good one which, while bringing to notice articles that might otherwise be missed by the busy surgeon or physician, should in the end save time and make it more possible to keep abreast of current views and research. It should prove to be a valuable publication.—S. Alan S. MALKIN.

A MANUAL FOR OCCUPATIONAL THERAPISTS ON THE REHABILITATION OF UPPER EXTREMITY AMPUTEES. By Thelma L. WELLERSON, A.M., O.T.R., Instructor in Occupational Therapy, College of Physicians and Surgeons, Columbia University; Director of Occupational Therapy, Institute for the Crippled and Disabled, New York. 11×8¾ in. Pp. vi+124, with many figures and tables. 1958. Iowa: Wm. C. Brown Book Company. Price $2.50.

This little book has been written for the guidance of those undertaking the rehabilitation of people who have lost an upper limb. The general approach shows much common sense and attention to detail, although we would regard the number of hours recommended by the author for training as small.

It is probably because we agree so wholeheartedly with most of the text that one or two items stand out for criticism. It is noted that the use of firm bandaging is still carried to the extent of attempting to mould the stump into a conical shape. It is surprising also that, in the preprosthetic stage, attention is not paid to finding tasks which make demands on function from the stump. For example, when the dominant hand is lost, the patient is taught to write with the remaining hand rather than to use a pencil strapped to the stump; and it is apparently not the practice to adapt equipment in the occupational therapy department so that the stump can be brought into use. There are one or two inaccuracies in terminology. For example, the term neuroma is defined as " Nerve tissue growing into or caught up in scar tissue *which causes a varying degree of pain . . .*" [my italics]; and scapular abduction is described as being enhanced by a particular form of harnessing, whereas it is the power available from the scapular abduction which is enhanced. In the historical section rather less than justice is done to British practice. The activated split hook was in fact introduced

as the standard multi-purpose terminal device in the early part of the 1914–18 war, and specialist work tools were available in addition. The book has been prepared rather in the form of " Do-it-yourself " instructions, which adds to clarity but inevitably introduces an element of dogmatism and repetition. The sketches and illustrations are in the main good and unequivocal. The charting of performance-checks against definite standards is an excellent principle.

The small criticisms apart, this book will be of interest and help to anyone working in this small and specialised field.—D. S. McKENZIE.

THE LIFE AND WORK OF THOMAS PORTER McMURRAY. By Bryan McFARLAND, Professor of Orthopaedic Surgery in the University of Liverpool. $8\frac{1}{2} \times 5\frac{1}{2}$ in. Pp. 12, with portrait photograph frontispiece. 1958. Liverpool: Liverpool University Press. Paper cover. Price 5s.

In this, the first McMurray Memorial Lecture, Bryan McFarland has given us the essence of the principles underlying the undoubted success of McMurray's practice and teaching of orthopaedic surgery.

It is presented in McFarland's own delightful and inimitable way, and those of us who had the good fortune to be closely associated with " Mac " as students and assistants will treasure it in a very special way, but others will find a great deal of interest in this account of the life and work of one of Robert Jones's greatest disciples, whose life ended so abruptly while he still had much to give.—Denys WAINWRIGHT.